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SCS Engineers
Reston, VA

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effect of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report reviews the technical and economic feasibility of resource recovery from selected waste streams which generate 100 tons per day or less. In addition, several research and developments options are suggested.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

A study was conducted to assess the applicability of various approaches to resource recovery to selected waste generators. The resource recovery systems and technologies were limited to those operating in the small-scale range, defined as less than 100 tons per day input, or those approaches considered to be low technology, defined as having more than 50 percent of operation and maintenance costs associated with labor, i.e., labor intensive. The generators included institutions, commercial sources, office building complexes, multi-unit residences and small cities.

An evaluation of seven potential systems led to the conclusion that two approaches were apparently technically and economically feasible for application to the waste generators. The two systems identified were modular incineration with energy recovery and source separation. A detailed analysis of the application of these two systems to the waste stream generators led to determination of applicability of either or both approaches to resource recovery to each of the generators. It was found that modular incineration is generally applicable to only the largest examples of the waste generators studied. Similar conclusions were associated with source separation; however, this approach was found more applicable to smaller situations than was modular incineration. Recommendation for future research and development included more thorough waste characterization of the sources studied, investigation of the effects of building design on resource recovery feasbility, and a further study of systems not currently considered as proven technology.

This report was submitted in fulfillment of Contract No. 68-03-2653 by SCS Engineers under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period January 6, 1978 to December 27, 1978. Work was completed as of January 15, 1979.

CONTENTS

Foreword iii
Abstract... iv
Figures.. vi
Tables..viii

I. Introduction.. 1
II. Waste Stream Generators...................................... 16
III. Technology System Evaluation................................ 40
IV. Applicability of Selected Systems to Waste Generators...... 79
V. Research and Development Needs............................... 116

Appendices

A. Conversion Table for Metric Units of Measure............... 122
B. Topical Bibliography... 123
C. Small-scale and Low Technology Resource Recovery Outside the United States 188
D. Summary of Information from Equipment Manufacturers........ 193
E. Component Descriptions...................................... 198
F. Energy Analysis of Alternative Resource Recovery Systems... 223
G. Modular Incinerator Selection Guide........................ 243

FIGURES

Number Page

1 Process Flow Diagrams - Ferrous Recovery and Compost Preparation 45

2 Process Flow Diagrams - Compost Preparation with Ferrous Recovery and RDF Preparation with Ferrous Recovery 51

3 Process Flow Diagrams - Incineration with Energy Recovery and Incineration with Energy and Ferrous Recovery 58

4 Process Flow Diagram - Source Separation 65

5 Air Freight Areas - Corrugated Recovery. 93

6 Airport Maintenance Base - Corrugated Recovery . . 94

7 Shopping Centers - Corrugated Recovery 96

8 Poisons - Corrugated Recovery 102

9 Universities - High-grade Paper Recovery 104

10 Office Building - High-grade Paper Recovery 107

11 Small Cities - Baled vs Non-baled Newsprint Recovery 112

12 Small Cities - Newsprint, Glass, Ferrous, and Aluminum Recovery 113

13 European Drop-off Container for Source Separated Glass 192

14 Air Classifer - Vertical and Horizontal 201

15 Rotary Drum Air Classifer and Air Knife 202

16 Typical Controlled Air Incinerator 212

17 Solid Waste Incinerator with Heat Recovery 214

18 Vertical Hammer Shredder 217

19 Shear Shredder 218

20 Rotary Trommel Screen 219

21 Modular Incineration Selection Guide for Small Cities 246

22 Modular Incineration Selection Guide for Airports. 247

23 Modular Incineration Selection Guide for Shopping Centers 248

24 Modular Incineration Selection Guide for Office Buildings 249

25 Modular Incineration Selection Guide for Garden Apartments 250

26 Modular Incineration Selection Guide for Universities 251

27 Modular Incineration Selection Guide for Prisons . 252

28 Modular Incineration Selection Guide for Hospitals 253

TABLES

Number Page

1 Approximate Waste Composition and Generation Rates for Selected Waste Generators 4

2 Example Cost Analysis: Modular Incinerator with Energy Recovery (100 TPD) 8

3 System Rating Criteria 11

4 System Rating 12

5 Feasibility of Resource Recovery Systems to Waste Generators 14

6 Composition of Airport Wastes 19

7 Composition of Shopping Center Wastes 22

8 Cost Analysis for A Representative Ferrous Recovery System (100 TPD). 46

9 Cost Analysis for A Representative Aerobic Compost Plant (100 TPD) 49

10 Cost Analysis for A Representative Aerobic Compost Plant with Ferrous Recovery (100 TPD) 53

11 Cost Analysis for A Representative Refuse-Derived Fuel (RDF) and Ferrous Recovery System (100 TPD) . . 56

12 Cost Analysis for A Representative Modular Incinerator with Energy Recovery (100 TPD) 60

13 Cost Analysis for A Representative Modular Incinerator with Energy and Ferrous Recovery (100 TPD) 62

14 Typical Preparation Requirements for Recyclable Materials 66

15 Assumptions for Source Separation Cost Analysis . . . 70

16 Cost Analysis for A Representative Small City Source Separation Program (100 TPD). 71

17 System Rating Criteria 73

18 System Rating 75

19 BTU and Fuel Savings Adjustment Factors 87

20 Resource Recovery Applicable to Airports 91

21 Resource Recovery Applicable to Shopping Centers 95

22 Resource Recovery Applicable to Hospitals 98

23 Resource Recovery Applicable to Prisons 100

24 Resource Recovery Applicable to Universities 103

25 Resource Recovery Applicable to Office Buildings 106

26 Resource Recovery Applicable to Garden Apartments 109

27 Resource Recovery Applicable to Small Cities 111

28 Energy Expenditure and Conservation for Selected Solid Waste Systems 224

SECTION I

INTRODUCTION

Approaches to the recovery of materials or energy from municipal wastes have been in operation for several years. This is particularly true of source separation and incineration with energy recovery. Most examples of these systems are associated with metropolitan areas with populations exceeding 100,000. Little information has, however, been compiled on procedures for recovering resources from specific waste generators within metropolitan areas or in smaller cities.

Section 8002(d) of the Resource Recovery and Conservation Act of 1976 (RCRA) required the U.S. Environmental Protection Agency (EPA) to conduct a study of small-scale and low technology resource recovery. This report contains the findings of that study.

The purpose of the project were:

- To compile a comprehensive bibliography on small-scale and low technology resource recovery systems
- To determine solid waste characteristics and collection and disposal practices of selected small waste generators
- To analyze small-scale and low technology resource recovery systems and evaluate applicability of the most feasible systems to the various waste generators
- To make recommendations for future research and development efforts

DEFINITION AND SCOPE OF PROJECT

Small-scale systems were defined as technologies which operate at a maximum capacity of 100 tons per day with less than 50 percent of the operating and maintenance costs devoted to labor.* Thus, these small-scale systems are essentially smaller versions of high technology approaches to resource recovery.

* Metric units of measure were not used in this report. It was felt that the user community was more accustomed to English units and that the degree of actual use of this report would decrease if metric units were reported. The use of English units in lieu of metric was approved by the Project Officer. A conversion table is included as Appendix A.

The small-scale systems' input would be mixed wastes from the sources identified with the output including separated materials and/or recovered energy.

Low technology systems were defined as having 50 percent or more of the operating and maintenance costs associated with labor. No limitations were placed on the input capacity of low technology systems. The principal low technology system in the United States is source separation; however, many approaches to material recovery could fit the definition if they were oriented to manual labor rather than mechanized operations.

The project focused on several types of small volume waste generators including the following:

- Institutions
    - -- Hospitals
    - -- Prisons
    - -- Universities
- Office Buildings
- Commercial Sources
    - -- Airports
    - -- Shopping Centers
- Multi-unit Residences
    - -- Garden or Low-rise Apartments
    - -- Mobile Home Parks
- Small Cities

The inclusion of some of these waste generators was required by the legislation directing this study. Others were included because it was felt that they were potential candidates for resource recovery operations. Some of the above sources had easily segregated portions of the waste streams containing materials amenable to recovery. Examples include the recovery of corrugated cardboard from prisons, universities, and shopping centers. Some of the waste generators were considered as likely on-site consumers of energy recovered from the incineration of their wastes. These included hospitals, prisons, universities, airports, shopping centers and low-rise apartments. Small cities were included essentially to complete the scope of potential resource recovery from municipalities.

APPROACH

Waste Characteristics and Generation Rates

In order to assess the applicability of resource recovery to these waste generators, information was needed on solid waste generation rates, waste composition, and typical collection and disposal practices. A search of the literature yielded very little information on the generators with the exception of small cities, office buildings, and hospitals. This lack of published data necessitated limited, informal, on-site waste characterization studies supplemented by telephone surveys.

The literature review and data collection efforts yielded the approximate waste composition and generation rates shown in Table 1. It should be noted that some of the waste generators were divided into subcategories, e.g., four different types of operations at airports and three different sizes of shopping centers; however, only one example of each source is shown in Table 1. Of particular interest were the units of measure associated with overall waste generation rates. Most of the literature reported some factor of waste generation per day or week, related to a measure of size or level of activity at the facility. The size measurement was often based on the number of persons using the facility, but also included floor areas (for shopping centers) and number of paid staff (hospitals). Composition data was taken from a limited number of sources in most cases, as was the overall waste generation rates. The effort to collect information on waste stream generators and applicable resource recovery technologies led to the development of a topical bibliography (Appendix B).

The generation rates were found to be quite variable, depending upon the type of activity conducted. This was especially true of hospitals and prisons. Within hospitals such "heavy care" units as surgery and maternity had high generation figures, whereas, "light care" units such as psychiatric and administrative units generated much less waste. The generation rate for prisons is associated with the residential and administrative aspects of these institutions and did not include any wastes generated by industrial or agricultural activities. The fairly extensive use of disposable items is reflected in the generation rate and the quantities of paper and plastics.

The generation rate at universities depends upon the types of wastes included. The generation rate shown does not include wastes from agricultrual or medical schools or landscaping, demolition, and construction wastes. Likewise, it was noted that sources of recyclable materials at universities, particularly paper, were easy to identify, with approximately 80 percent of all paper coming from office and classroom areas; a high percentage of this paper is recyclable.

TABLE 1. APPROXIMATE WASTE COMPOSITION AND GENERATION RATES FOR SELECTED WASTE GENERATORS

	Percent of Total (Weight Basis)							
Type of Material	Airport Passenger Terminal	Regional Shopping Center	Hospitals	Prisons	Universities	Multi-Unit Residences	Office Buildings	Small Cities
Paper	71	28	40	37	55	35	87	29
Corrugated		52		22	10			
Glass	4	1	6	1	8	12	1	10
Metal	6	3	2	16	7	10	7	10
Plastics	5	8	15	8	3	5	1	3
Organics	5	2	25	10	10	27	4	38
Wood	3	2	12	6	7	11		4
Miscellaneous	6	4						6
TOTAL	100	100	100	100	100	100	100	100
Overall Waste Generation Rates	0.5 lb per passenger per day	200 lb per 1000 sq. ft. of gross leasable area per week	2 to 4.5 lb per paid staff member per day	4.5 lb per inmate per day	1 lb per student per day	2.7 lb per resident per day	1.5 lb per office worker per day	3.5 lb per person per day

Office buildings are notable for the very high percentage of paper. Much of this is high-grade paper and computer cards and printout which often command premium prices. Numerous office buildings of governmental agencies and private firms practice source separation of high-grade paper. A relatively small amount of organics is generated by office buildings without food service facilities. The percentage of organics increases significally for office buildings with food service facilities.

Relatively large quantities of organics are shown coming from multi-unit residences and small cities. This is due to the fact that both garbage and landscaping wastes are included.

The data in Table 1 are derived from a relatively small sampling of information from the specific sources, with the exception of hospitals, office buildings, and small cities. Thus, in assessing the feasibility of resource recovery in a specific situation, a waste characterization study should be completed to determine the composition and quantity of wastes being generated at that location.

Technology System Evaluation

System Criteria--

The next step in this study was to collect information and evaluate the current state-of-the-art approaches to resource recovery for their applicability to the waste generators selected. Information concerning the state-of-the-art, applicability, and costs associated with material processing components was obtained from a variety of sources including published material and through direct contact with equipment users and manufactuers. No site visits to resource recovery operations were made during this project. Gathering of information was not limited to the United States. As part of the project, the First World Recycling Congress was attended. The five-day Congress was held in Basel, Switzerland and included technical papers and equipment displays from some 20 countries worldwide. A synopsis of the results of attending the Congress is included as Appendix C.

Unit process components considered technologically proven at the 100 ton per day level or less were assembled into resource recovery systems applicable to the waste generators. Operational and technical aspects of each system were analyzed and a cost analysis developed which was used to estimate net disposal costs per ton of input.

For purposes of the study components of resource recovery systems were considered technologically proven, if, at 100 tons per day or less, the component has:

- Operated at full scale for a least one year

- Produced the desired product in a marketable form.

This definition eliminated components in the pilot scale or in shake-down tests. Likewise, it eliminated those components generating a product that is not marketable; i.e., no market exists for the material or has existed in the very recent past. The above definition was applied to various resource recovery system components. The components of small-scale systems initially considered include the following:

acid hydrolysis conversion units
air classifiers
aluminum magnets
composting equipment
froth flotation units
magnetic separators
methane digesters
modular incinerators
pyrolytic units
shredders
trommel screens

Application of the criteria for a component to be technologically proven prior to further consideration led to the elimination of several components. These are listed below along with the reason for elimination:

- Acid hydrolysis conversion unit -- considered to be in experimental or pilot stage.

- Aluminum magnets -- unable to assess effectiveness of the one operational unit due to small amounts of aluminum in waste stream. Other installations considered to be in shake-down status.

- Froth flotation -- considered to be in shake-down status. Although high purity product (99%) has been achieved, it still does not meet container industry specifications.

- Methane digesters -- pilot scale plant for solid wastes and sewage sludge is in operation. No system in operation at commercial scale.

- Pyrolysis -- two small operating units considered to be in demonstration or shake-down status.

The remaining components were "assembled" into six, small-scale systems for further analysis:

- Ferrous Recovery

- Compost Preparation

- Compost Preparation with Ferrous Recovery

- RDF Preparation with Ferrous Recovery

- Incineration with Heat Recovery
- Incineration with Heat and Ferrous Recovery

Application of System and Cost Analyses--

Next, scenarios were developed describing the features of each of the above systems, their limitations, and their applicability. This led to the development of a cost analysis of each. In order to evaluate the systems as uniformly as possible, common assumptions were applied, as follows:

- All systems to be operated at 100 tons per day input.
- Hauling and disposal costs for non-recovered waste from the processing facility were estimated at $7 per ton.
- Uniform costs for labor were applied.
- An average mid-1977 market value for recovered material was used.
- The value of energy recovered was equated to the cost of the least expensive fossil fuel from which the same amount of energy could be recovered.

An example cost analysis is shown in Table 2. Specific assumptions associated with modular incineration are shown in the table.

In the area of low technology systems only source separation was considered, and a scenario was developed describing a typical source separation program applicable to a small city. The great variability of source separation and its applicability to several of the waste generators precluded the development of scenarios and the resulting cost analyses of more than one source separation program.

Overall Evaluation--

As a result of an overall evaluation considering costs and other factors, modular incineration with heat recovery (without ferrous recovery) and source separation emerged as the highest rated systems. Additionally, these were the systems with the lowest cost per ton. An area of potential concern for modular incinerators is air pollution control. While several installations have met State standards, it is possible that some units will require external air pollution control devices. The approach used in evaluating the systems is described below.

TABLE 2. EXAMPLE COST ANALYSIS: MODULAR INCINERATOR WITH ENERGY RECOVERY[1] (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Incinerator and boiler, complete in place[2]		$1800	15	0.117	$210
Auxiliary Equipment		50	5	0.250	13
Small Front-End Loader	40				
Office Furniture, Refuse Bins	10				
Construction & Land		396	20	0.101	40
Building: 9500 ft^2 @ \$30/ft^2	288				
Site Development: 20% of bldg.	58				
Land: 5 acres @ $10,000/acre	50				
TOTAL		$2246			$263
OPERATING COSTS ($1,000)					
Labor:[3] 4 operators @ $48 1 supervisor @ $16					64
Supplies: 3% of labor & maint.					3
Energy:[4] Supplemental fuel		$36.0			
Mobile loader		3.2			
Lighting		0.7			
Heat building		1.3			41
Maintenance: 3% of total capital costs					66
Miscellaneous: (taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					22
TOTAL					$196
TOTAL ANNUAL SYSTEM COSTS ($1,000)					$459
COSTS/REVENUES PER TON ($/ton)					
System Cost					$ 17.65
System Revenue[5]					8.08
Net System					9.57
Landfill[6]					2.11
Total Net					$ 11.68

TABLE 2. (Continued)

Footnotes:

[1] Data calculated by SCS Enginners from literature and vendor sources.

[2] Includes 5 25-TPD units. Incinerators are designed to operate on a 24-hour basis. The extra unit provides reserve capacity for maintenance.

[3] Operators are on duty for 8-hour shifts. The shifts are split to allow for continuous operation, 5 days per week. Wage rate is $5.80 per hour, which includes fringe benefits of 15 percent. The supervisor is on duty for one 8-hour shift at $7.80 per hour.

[4] Energy: Supplemental fuel is consumed at a rate of 5 percent of the BTU value of the input refuse. Operating conditions:

• Thermal value of refuse	5,000 BTU/pound
• Supplemental fuel	Natural Gas
• Cost of gas	$0.2776/therm
• Thermal value of therm	100,000 BTU

Mobile Equipment - operation conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[5] Revenue Factors:

• Percent combustibles in wastestream	80%
• Recovery rate	90%
• Market value: substitute value of coal	$1154/100 tons of combustible refuse @ 5000 BTU/pound

[6] Cost Factors:

• Weight Reduction	70%
• Cost to haul to landfill and disposal	$7/ton

Those systems with apparent technical and economic feasibility and desirability for application to the waste stream generators were subjectively evaluated. In order to evaluate the systems, rating criteria were selected that represent the characteristics (other than economics) of greatest concern to small waste generators. Site-specific factors, such as public acceptance, were not rated, although they are extremely important. The criteria selected were essentially qualitative in nature and thus were rated accordingly. Three major categories of criteria were performance, environmental acceptability, and marketability of recovered product. These were further subdivided into more detailed criteria; an explanation of the approach used to rate each is shown in Table 3.

Consideration of information available in the literature and through contacts with system owners and operators lead to the evaluation of the systems using the above criteria. The results are shown in Table 4. A review of the ratings in Table 4 led to the elimination of several systems from further evaluation as to their applicability to the waste stream generators. Reasons for eliminating these systems are summarized below:

- RDF -- high costs, market uncertainty, and possible problems associated with storage and transport of the material
- Ferrous recovery -- high costs and price fluctuations for recovered ferrous
- Compost -- high costs, large capital investment and virtually no market for the product.

Application of Technologies to Waste Stream Generators

The applicability of modular incineration or source separation or a combination of the two to any of the waste stream generators was then evaluated on the basis of overall system costs. The inclusion of resource recovery was considered appropriate and feasible in all situations where the overall waste management costs with the inclusion of resource recovery were equal to or less than the waste management costs prior to any change. Costs for collection and disposal of wastes from all sources except small cities was estimated to be \$28 per ton, which includes rental of bulk waste containers. For small cities the disposal costs of \$7 per ton was used. It was assumed that the city would have to collect the wastes whether they used landfill disposal or hauled it to a resource recovery facility; thus, only the cost of disposing of unrecovered material impacted on this analysis. The results of this analysis indicated situations for waste stream generators in which one or the other or

TABLE 3. SYSTEM RATING CRITERIA

I. PERFORMANCE

A. Reliability: System and components proven to perform dependably and with minimum down-time.

Rating	Description
High	Proven performance with high reliability
Medium	Adequate performance with adequate reliability
Unacceptable	Inadequate performance with inconsistent reliability

B. Degree of Waste Volume Reduction

Rating	Description
High	>60%
Medium	30-59%
Low	0-29%

C. Freedom from Maintenance/Simplicity

Rating	Description
High	Simple; minimal skills required for operation; few or no moving parts
Medium	Moderate; intermediate in mechanical complexity; operation requires some degree of skill and/or training
Low	Complex; involves sophisticated mechanical equipment; skilled and trained operators required

II. ENVIRONMENTAL ACCEPTABILITY

A. Meets all minimum standards for air, noise, water and land pollution

Rating	Description
Acceptable	Complies with minimum standards
Unacceptable	Does not meet standards

B. Maximizes resource recovery within technological limits

Rating	Description
High	Recovers maximum number of resources; >60% of waste
Medium	Recovers moderate number of resources; 30-59% of waste
Low	Recovers few resources; <29% of waste stream

III. MARKETABILITY OF RECOVERED PRODUCT(S)

Rating	Description
High	Product(s) have ready markets
Medium	Product(s) are somewhat marketable, but prices subject to cyclical swings
Low	Product(s) difficult to market or have very low value

TABLE 4. SYSTEM RATING

	System Rating Criteria (100 TPD System)						
	Reliability	Waste Volume Reduction	Freedom from Maintenance; i.e., Simplicity	Environmental Standards	Resource Recovery	Marketability of Product(s)	Net Cost/Ton*
Ferrous Recovery	Medium	Medium	Low	Acceptable	Low	Low	$15.38
Compost	Medium	Medium	Low	Acceptable	Medium	Low	26.70
Compost with Ferrous Recovery	Medium	High	Low	Acceptable	High	Low	26.05
RDF with Ferrous Recovery	Medium	High	Low	Acceptable	High	Medium	13.61
Incineration with Energy Recovery	High	High	Medium	Acceptable**	High	High	11.68
Incineration with Ferrous and Energy Recovery	Medium	High	Low	Acceptable**	High	Medium	11.95
Source Separation	Medium	Medium	High	Acceptable	Medium	Medium	8.16

* Cost of operating system minus revenues plus disposal of non-recovered material.

** May require external air pollution control equipment.

both approaches to resource recovery was less expensive than current disposal and thus considered feasible. Overall feasibility is shown in Table 5.

As can be seen from the table, there are only a few situations in which either modular incineration or source separation or a combination of both were unequivocally considered feasiblé for a particular waste generator. In most instances, resource recovery was considered viable only for the largest examples of each waste generator, thus exemplifying some economies of scale associated with these operations. For those waste generators where the combination of both approaches to resource recovery was indicated as feasible, it should be understood that the decision was based upon meeting the more stringent of the requirements for either incineration or source separation. For example, both modular incineration and source separation would be considered feasible in office buildings if there is at least 4,000 employees.

Only multi-unit residences (low-rise apartments and mobile home parks) were not considered amenable to resource recovery. Neither normally has enough residents to generate the required quantity of materials or mixed wastes. Likewise, there are virtually no examples of situations where recovered energy could be used in the mobile home park or in an apartment building, except possibly a large apartment complete with a central boiler/hot water system.

Particular note should be made of the indicated feasibility of modular incineration to small cities. The disposal cost of $7 per ton was used for small cities because it was used earlier in the cost analyses of the seven systems originally considered technologically proven. This cost may be too low, particularly for small disposal operations; e.g. 100 TPD, that are truly sanitary landfills. Likewise, the value of the energy recovered at any particular location may be greater than the $1 per million BTU assumed in Table 2. Several small cities are cost-effectively using this method of resource recovery.

It cannot be overemphasized that the feasibility of any approach to resource recovery is highly site-dependent. The evaluations made in the report were based upon assumed costs for solid waste management and values of recovered energy and materials. There are, and will be, exceptions to the findings of this report. Thus, it is imperative that any waste generator evaluating resource recovery make an individual feasibility study conducted by competent, experienced personnel prior to making any commitments.

RESEARCH AND DEVELOPMENT NEEDS

The final objective of the project was to make recommendations for further expenditures of efforts and funds in the area

TABLE 5. FEASIBILITY OF RESOURCE RECOVERY SYSTEMS TO WASTE GENERATORS

Waste Generator	Modular Incineration w/ Energy Recovery	Source Separation	Both
Small Cities	If disposal costs are more than $12 per ton	Newspaper--above 13,000 population @ 30% participation Fe, Al, glass and newspaper--above 22,000 population @ 30% participation	No
Office Buildings	If more than 4,000 employees	High-grade paper down to 75 employees	Yes
Airports	At major airports	Corrugated, sometimes	Yes
Shopping Centers	Yes	Corrugated	Yes
Low-rise Apartments	No	No	No
Mobile Home Parks	No	No	No
Prisons	Only the largest; 1,500+ inmates	Corrugated	Yes
Hospitals	If more than 500 beds	No	No
Universities	If more than 5,000 students	High-grade paper	Yes

of research and development associated with small-scale and low technology resource recovery. Three areas were recommended for further study:

- In-depth waste characterization studies of small waste generators included in this study, especially shopping centers, prisons, universities, and airports.

- Studies to determine how changes in building design could facilitate and encourage resource recovery. Shopping centers appear to be the most fruitful area for these efforts.

- Analysis of resource recovery systems in the developmental stage with a likelihood of successful application to small generators. The systems recommended for further analysis include production of RDF and the application of vermicomposting to solid waste management. When the production of RDF at large resource recovery facilities increases and the use of this fuel increases, markets for RDF will develop and become stable. This may give rise to situations where small generators (probably small cities) near markets can economically produce RDF. Vermicomposting is essentially the only low technology resource recovery system that is applicable to mixed wastes. Little is known about this approach which appears applicable to such waste stream generators as prisons, universities, and small cities.

SECTION II

WASTE STREAM GENERATORS

This study concentrates on specific waste generators in five areas:

- Commercial Waste Streams
  - Airports
  - Shopping Centers
- Institutional Waste Streams
  - Hospitals
  - Prisons
  - Universities
- Multi-unit Residential Waste Streams
  - Garden or Low-Rise Apartments
  - Trailer Parks
- Office Complex Waste Streams
- Small City Waste Streams

These waste streams were selected because little work has been done on the applicability of small scale and low technology resource recovery systems to specific waste streams of this nature.

There is a major problem in trying to characterize these solid waste generators. The problem is the significant variations in the factors which determine waste generation and composition within each generator. These factors are outlined for each waste generator later in the chapter. The result of this problem is the difficulty of defining a representative generator in each category. This limitation should be noted by readers when examining the waste stream characteristics. The figures listed are felt to be representative, but there is considerable variation from these numbers. Such variations will, of course, affect the economic viability of any recovery systems, which might be used by those generators.

COMMERCIAL WASTE STREAMS

Airports

Waste Stream Characteristics--

The quantity and composition of the solid waste generated at an airport is affected by several variables. The significant ones are:

- Size
- Volume of air freight
- Volume of passenger loading
- Amount and level of construction, demolition, and maintenance activities taking place at the airport

Wastes can also be classified by type of service within an airport complex. Typical categories are:

- Passenger terminals
- Air freight area, including mail service facilities
- Aircraft service centers, providing aircraft supplies, such as food, and minor maintenance, as well as interior cleaning services
- Aircraft maintenance bases, providing services for major repairing and overahaul of aircraft

Published studies on solid waste generation rates in the four categories indicate the average rates are (1), (2):

- Passenger terminals - 0.5 pounds per passenger
- Air freight area - 7 pounds per ton of cargo
- Aircraft service center - 1 pound per passenger (Note: the generation rate on flights with food service average 2.5 pounds per passenger; whereas flights without food service average 0.5 pounds per passenger.)
- Aircraft maintenance base - 2 pounds per employee per day

These generation rates were substantiated through personal contact with solid waste managers of four airport complexes located in Washington, D.C., Baltimore, Maryland, and Milwaukee, Wisconsin, (Personal communications. Jack Stewart, Federal Aviation Agency, Dulles International Airport, Virginia. May 11, 1978; Pete Williams, National Airport, Washington, D.C. May 12, 1978; Date Watten, State Aviation Administration, Baltimore-Washington International Airport, Maryland. May 9, 1978; and Ted Meyer, Waste Management, Inc., Milwaukee, Wisconsin. May 15, 1978).

Paper is the dominate waste material in each service category, except for aircraft service centers, Table 6. Organics, primarily food waste from passenger meals, was the major component from the aircraft service centers.

Typical Collection Practices--

In-house handling of waste generally is performed by each tenant (airlines and vendors). The major exception is the common areas of the passenger terminal, such as ticket counters and restrooms which are serviced by airport maintenance personnel. Wastes are stored initially at generation sites, then collected by custodial personnel, and again stored at an intermediate accumulation point such as dumpsters, barrels, or compactors prior to final collection by truck. One exception is in the aircraft service center. Garbage generated during in-flight meal service is separated from other waste materials and fed into garbage disposals.

Frequency of collection varies by area in an airport complex. The passenger terminal has the most frequent collection of wastes. At high volume airports, the terminal area might be serviced as often as four to five times per day, while other areas within the complex may be serviced several times a week.

A survey of 36 airports found that 58 percent were serviced entirely by private contractors, 33 percent were serviced by a combination of private handlers and airport maintenance crews, and the remaining nine percent were serviced by a public waste management agency or by airport personnel (3). The survey also reported that 61 percent of the airport tenants were responsible for arranging for their own waste collection; 8 percent had an airport authority negotiated contract with the tenants and the remaining 23 percent of the airports reported some other method of arranging for refuse collection.

Typical Disposal Practices--

No quantitive studies have been done which show how airport wastes are disposed. However, landfill appeared to be the most common method of disposal. In addition, solid waste at some airports is incinerated at either on-site or municipal incinerators.

TABLE 6. COMPOSITION OF AIRPORT WASTES

Type of Material	Percent of Total (Weight Basis)			
	Passenger Terminal	Air Freight	Aircraft Service Center	Aircraft Maintenance Bases
Paper	71	46	32	51
Glass	4	3	4	10
Metal	6	8	12	6
Plastic	5	10	10	10
Wood	3	17	2	5
Organics (e.g., food waste)	5	3	34	15
Miscellaneous	6	13	6	4
TOTAL	100	100	100	100

Source: Metcalf and Eddy, Inc. Analysis of airport solid waste and collection systems. U.S. Environmental Protection Agency, Washington, D. C. 1973. pp 40 (Available from National Technical Information Service [NTIS], 5285 Port Royal Road., Springfield, Virginia 22161 as PB 219-372).

Shopping Centers

Waste Stream Characteristics--

Shopping centers can be classified by size and type of function. Standard classifications are (4):

	Average Size	Range
Classification	Sq Ft of Gross Leasable Area	Sq Ft of Gross Leasable Area
Neighborhood	50,000	30,000-100,000
Community	150,000	100,000-300,000
Regional	400,000	300,000-1,000,000+

Solid waste generation rates and composition vary by shopping center classification due to the different types of services typically offered. Neighborhood shopping centers are designed primarily for the sale of food, convenience goods, and personal services. The principal tenant in terms of gross leasable area is commonly a supermarket. A less than full-line department store and a supermarket are usually the principal tenants in a community shopping center. Regional shopping centers are characterized by one or more full-line department stores of at leas 100,000 square feet of gross leasable area, and a variety of other stores offering a range of services. Larger centers, particularly regional centers, tend to have consistent mix of tenants. Therefore, the quality and composition of the waste generated at these shopping centers is relatively consistent. The types of tenants are more varied in the smaller centers than in the regional centers. Waste stream characteristics from smaller shopping centers also tend to be more variable.

In addition to size and type of tenants, other variables which affect the quantity and composition of shopping center solid waste are:

- Sales volume
- Number of hours of operation
- Number of employees

Published studies of solid waste management at shopping centers provided limited and vague data on waste characteristics (5,6,7). Therefore, an informal telephone survey of waste collection contractors was conducted in the Washington, D.C., New Brunswick, New Jersey, and Milwaukee, Wisconsin areas. On-site visits were also made to five shopping centers in the Washington, D.C. area, (Personal communications. Ted Meyer, Waste Management, Inc., Milwaukee, Wisconsin. May 15, 1978; Gene Conlon, Jersey Sanitation, New Brunswick, New Jersey. May 16, 1978; Sam Ziff, Browning-Ferris Industries, Merrifield, Virginia. May 17, 1978; and Edward Bailey, B and B Trash Service, Waldorf, Maryland. May 17, 1978). Survey data indicate a weekly waste generation rate of approximately 200 pounds per 1000 square feet of gross leasable area in regional shopping centers. Based on on-site observations and surveys, the weekly waste generation rate per 1000 square foot of gross leasable area for community and neighborhood shopping centers was estimated to be approximately 175 pounds and 150 pounds respectively.

Corrugated was the primary constituent in all these categories of shopping centers, Table 7. The percentage of corrugated to the other components in the waste stream did vary by category. The highest percentages were at neighborhood regional centers which receive more bulk shipments.

Typical Collection Practices--

Wastes usually are accumulated at the initial point of generation within a store. The wastes then are transported by a store employee to an intermediate storage point located either outdoors or, in the newer regional shopping centers, in the underground truck tunnel loading dock area. The shopping center management is responsible for collecting the trash produced in the common areas, such as parking lots and shopper's walkways.

Generally, the intermediate storage points are dumpsters and compactors. The principal tenants in shopping centers, particularly in community and regional centers, use individual compactors as these tenants are high volume retail outlets, generating significant quantities of waste. Collection/disposal charges are on a per pull basis with the compactor bodies pulled at regularly scheduled intervals whether full or not.

Some shopping centers provide stationary compactors for the use of all tenants. Waste management charges are assessed each tenant according to usage of the compactor. Each tenant is given a different key to the compactor and is charged for each time the compactor is activated using their key. This approach encourages reduction of the amount of waste taken to the compactor and thus could be incentive to resource recovery. However, it also may encourage littering and the use of public (shoppers') waste containers by tenants.

Shopping centers are serviced by waste handlers in either of two ways: (1) each tenant arranges for waste collection independent of the other tenant or (2) the shopping center management contracts for one waste hauler to service the entire center. The first option is the traditional method. The trend, particularly at the new regional shopping centers, appears to

TABLE 7. COMPOSITION OF SHOPPING CENTER WASTES

	Percent by Total (Weight Basis)		
Type of Material	Neighborhood	Community	Regional
Paper	25	25	30
Corrugated	45	50	50
Glass	4	2	1
Metal	5	4	3
Plastic	6	7	7
Wood	2	2	3
Organics (e.g., food waste)	4	4	2
Miscellaneous	9	6	4
TOTAL	100	100	100

Source: SCS Engineers. On-site inspection of shopping center discards in the Washington, D.C. metropolitan area. May, 1978.

be toward single contractual arrangements. This is due to the limited space available in the underground delivery area. This area can become congested while deliveries are being made and the presence of several waste handlers in the truck tunnel during this period compounds the congestion. A single contract hauler enables the shopping center management to coordinate the times when refuse will be collected. Scheduling of waste collection at off-peak times for merchandise delivery reduces congestion in the truck tunnel.

At several of the shopping centers surveyed, corrugated was segregated for recycling. This activity takes place primarily at supermarkets in neighborhood and community shopping centers. Although significant quantities of corrugated are discarded at regional shopping centers, none of the centers surveyed were separating this material for recycling. The primary obstacles appear to be a lack of suitable storage space and the problem of arrangements with multiple contractors.

Typical Disposal Practices--

No quantitative studies have been done which show how solid wastes from shopping centers are disposed. However, landfill appeared to be the most common method of disposal.

INSTITUTIONAL WASTE STREAMS

Hospitals

Waste Stream Characteristics--

Numerous studies have been done on solid waste generation and handling practices in hospitals, see Bibliography. These studies indicate that many variables affect the quantity and composition of the solid waste generated. This variability results from a number of factors:

- Number of beds
- Community population characteristics
- Presence of specialized facilities and services
- Utilization of hospital (number of surgical procedures, live births, outpatient visits, etc.)
- Number of employees and trainees
- State license and accreditation by the Joint Commission on Accreditation of Hospitals (both tend to correlate with increasing quantities of wastes)
- Use of disposables and single-use items

Studies on waste generation in hospitals have shown an extremely wide range of generation rates. The range was from 3 pounds per patient per day to 20 pounds per patient per day or more (8). Researchers at the University of Minnesota developed the concept of "equivalent population", in order to develop a more reliable indicator of solid waste generation which accounts for the variability among hospitals (9). The concept is based on the average population present in a hospital for each 8-hour shift over 24 hours a day 7 days a week counting out-patients at one-half value. The "equivalent population" figure allows for esimation of waste generation for hospitals of different sizes and different types of medical care. On this basis, waste generation nationwide averaged between 2 and 5.5 pounds per capita per day.

The equivalent population method permits hospital designers to predict the amounts of waste generated for various types of hospitals. This method cannot predict the quantity of wastes produced by the individual units of each hospital. A study by a research team at West Virginia University derived a series of simple mathematical equations that predict wastes for units within hospitals (10). The main variable for most patient-care units proved to be the total paid staff for a 24-hour period including nurses, aids, clerks, orderlies, housekeepers, and maids but excluding doctors. A correlation was found between the number of staff and the quantity of wastes produced which is indicated below:

Source	Generation Rate (lb per day)
Heavy-care units (surgery, burns, maternity)	4.47 times number of paid staff for those units
Light-care units (psychiatric, neurology)	2.77 times the number of paid staff for those units
Administration and support units	2.11 times the number of paid staff for those units
X-ray, emergency room, central supply	0.48 times number of patients treated
Laboratory and clinics	0.19 times number of tests or patients
Kitchen, cafeteria	1.5 times the number of meals served

Due to the variability among hospitals in the use of disposable and single-use items, the composition of hospital solid waste are highly variable. In general, paper products compromise the largest portion of the waste stream, see below. These products are mainly single-use disposable items. A large number of single-use items are made from plastic, which is the third largest component of hospital waste. Organics, primarily food wastes from patient meals, makeup the second largest percentage of the waste stream (11).

Type of Material	Percent of Total (Weight Basis)
Paper	40
Glass	6
Metal	2
Plastics	15
Organics (e.g., food waste)	25
Miscellaneous	12
TOTAL	100

Approximately 4 percent of the waste is infectious, a great deal of which is mixed with the combustible rubbish. In addition, there are various hazardous wastes, i.e., biological, radioactive, and chemical wastes, plus sharp items such as disposable needles, that require separate and special handling. Because attempts to separate these special wastes often fail, all hospital wastes are considered potentially contaminated.

Typical Collection Practices--

In-hospital waste handling includes waste collection from points of generation and transport to one or more central storage locations. Most waste is initially deposited in small receptacles located near the points of generation. In recent years, most of these receptacles have been equipped with disposable plastic liners which facilitates more efficient transfer of waste. At suitable intervals, the waste is transferred, usually by housekeeping personnel, to larger containers, or intermediate accumulation points, such as garbage cans, empty oil drums, laundry hampers or carts. This intermediate storage may be located in utility rooms, trash rooms, or janitor's closets.

Alternate systems to collect and transport waste from intermediate accumulation points to central storage locations include:

- Manual system
- Gravity chute/manual system

- Gravity chute/pneumatic tube system

- Pneumatic tube system

Most hospitals use manually propelled carts while only a few hospitals use the more sophisticated mechanical systems. However, inability to thoroughly clean carts and problems with chutes such as contamination, fire hazards, spilling of wastes during loading, blockages, difficulties in cleaning, and odors, have resulted in a trend towards more sophisticated and expensive collection and handling systems. Stationary compactors and dumpsters are the most common approaches to the central storage of hospital wastes prior to collection.

Typical Disposal Practices--

Hospital wastes are disposed in a number of ways, usually by the hospital's maintenance or engineering department. Infectious or pathological wastes typically are incinerated on-site in a specially designed unit. Some portions of the non-infectious waste stream are also often burned in the same or other incinerator.

A survey of 80 hospitals in 1973 found that 70 used incinerators to dispose of some wastes (12). In recent years, the use of incineration has declined, primarily to the inability of older on-site incinerators to meet air pollution standards. Newer starved air incinerators, which can meet air quality standards in some states, appear to have reversed this trend away from incineration.

No quantitative studies have been done on how hospitals ultimately dispose of their wastes. Landfill appeared to be the most common method of disposal.

Prisons

Waste Stream Characteristics--

The quantity and composition of the solid waste generated at a correctional institution is affected by several variables:

- Number of inmates

- Staff size

- Type and level of activity within the institution (e.g., prison industry and level of security)

The waste generated at a correctional institution can be divided into three categories; residential waste, industrial waste, and support services waste. Residential and support services wastes will be generated at all correctional facilities.

Industrial wastes are only produced at those institutions which sponsor such activities.

Included in the residential category are such items as food preparation wastes and wastes from daily prisoner activity.

Overall, the residential wastes are similar to residential wastes from civilian communities. However, there are identifiable sources of each constituent of this waste stream. Food preparation areas and dining halls are sources of garbage, corrugated, metal cans, and glass. Most garbage is disposed through garbage grinders. Wastes from cell blocks and other prisoner areas tend to have a high content of paper and plastic including newspaper, food wrappers and disposable items such as cups. The composition of discarded industrial materials is dependent on the type of industrial activity, if any, taking place within the institution while the support services include wastes from administrative offices, medical or other services.

Only one published study contained data on the characteristics of solid waste from correctional institutions (13). This study examined the five correctional institutions managed by the County of Los Angeles. None of these facilities were involved in any industrial activity. The average daily rate of solid waste generated was 3.6 pounds per inmate with a range of 2.4 to 5.1 pounds per inmate per day. However, this information may be dated, as the study was published in 1972.

Current data on waste generation were collected from the Bureau of Prisons of the U.S. Department of Justice and the Department of Corrections of the District of Columbia. The data from the Bureau of Prisons, which operates at least one industrial activity at each prison, indicated the average daily solid waste generation rate is 9.6 pounds per inmate. Daily waste generation per inmate ranged from a low of 6.8 to a high of 11.5 pounds. These figures include industrial as well as residential and support service wastes (14).

To derive estimates for residential and support service wastes characteristics, a site visit was conducted at the Washington, D.C. correctional facility. Residential and support service wastes generated at this facility were estimated to average 4 to 5 pounds per inmate per day (15). Solid waste managers at four Federal facilities felt that this figure approximates generation rates at their facilities, (Personal communications. R. McFenie, Bureau of Prisons, Alderson, West Virginia. May 5, 1978; C. Brown, Bureau of Prisons, Morgantown, West Virginia. May 5, 1978; Sharon Gill, Bureau of Prisons, Danbury, Connecticut. May 8, 1978; Philip Loprisette, Danbury Cartering, Danbury, Connecticut. May 8, 1978; and G. Marshall, Bureau of Prisons, Petersburg, Virginia. May 9, 1978.)

Paper is the largest component of residential and support services wastes in prisons, see below. The other major components are corrugated shipping boxes, which result from bulk shipment of supplies, and metals from food and beverage containers. An extensive use of disposable items associated with food service was noted during the visit to a prison. This is reflected in the relatively high percentage of paper and plastics. It also helps explain the relatively high generation rate for prisons as does the fact that the generation rate is based on the number of inmates when, in fact, administrators, guards, and other support personnel also generate waste.

Type of Material	Percent of Total (Weight Basis)
Paper	37
Corrugated	22
Glass	1
Metal	17
Plastics	8
Organics (e.g., food waste)	10
Miscellaneous	5
TOTAL	100

Industrial activities were also surveyed during the site visit and conversations with Federal prison solid waste managers. However, because these activities are highly site specific, no generalizations can be made concerning industrial waste generation.

Typical Collection Practices--

Refuse initially is stored in cans or barrels in the areas of waste generation, such as the kitchen and shops. On a regular basis, the containers are transported (usually on hand carts) to intermediate storage containers prior to pick-up. This transport of wastes usually is done by inmates. Dumpsters are the predominant method of storage prior to collection. Collection service is provided on a contract basis at the majority of the institutions surveyed. The frequency of collection varies by section of the institution. In some sections such as the kitchen, refuse is collected daily, while collection rates of once a week or less occur in some shop areas.

Typical Disposal Practices--

No quantitiave studies have been done on how prisons dispose of their wastes. Landfill appears to be the most common method of disposal. In the past, prisons operated their own landfill but due to stricter regulations, use of municipal or privately owned landfills is increasing. Many of the prisons surveyed practiced some recycling of industrial wastes on a limited basis. A unique recovery process - vermicomposting - is scheduled to handle the wastes from the Chester County, Pennsylvania jail. This process uses earthworms to convert organic wastes to a soil conditioner, (Personal communication. Robert Koke, GTA, Incorporated, Wilmington, Delaware. December 27, 1978).

University Wastes

Waste Stream Characteristics--

Many variables affect the quantity and composition of the solid wastes generated at universities. Much of this variability results from differences among universities and include such factors as:

- Size
- Location (urban, rural)
- Type of schools within the university (medical, agricultural, engineering)
- Number and type of university services (health services, libraries)
- Amount of construction, demolition, landscaping, and other related activities
- Proportion of students in university residence halls compared with commuters and off-campus residents

Wastes can also be classified by source within the university. Typical categories follow:

- Residence halls and food service facilities
- Offices, classrooms, labs and libraries
- Physical plant operations
- Special sources such as agricultural research areas

Published studies of the solid waste characteristics at four universities showed a range in solid waste generation rates from 0.86 pounds per student per day to 2 pounds per student per day (16), (17), (18), (19). This variability can be explained by the presence of special category wastes at some schools, but not at others. For example, the University of Illinois generated 2 pounds per student per day. This figure includes wastes from the agricultural school, the veterinary school (animal carcasses, manure and bedding) and landscaping, demolition and construction wastes. To supplement the published data, a telephone survey was conducted, (Personal communication. Elwood Gross, University of Maryland, College Park, Maryland. May 9, 1978; R. Hudson, American University, Washington, D.C. May 9, 1978; and Ted Meyer, Waste Management, Inc., Milwaukee, Wisconsin. May 15, 1978). The average solid waste generation rate from the first three typical waste categories was determined to be about 1 pound per student per day. The average could increase by 0.5 to 1 pound per student per day depending on the nature and quantity of special wastes produced. This adjustment factor should be determined for each university on an individual basis.

Paper is the major constituent of university wastes, see below. The largest component of the paper segments is recyclable paper, mainly high-grade office paper. The second largest contributor to university wastes are organic materials. These materials are primarily food wastes.

Type of Material		Percent of Total (Weight Basis)
Paper		65
Recyclable Paper	30	
Non-recyclable Paper	25	
Corrugated	10	
Glass		8
Metal		7
Plastics		3
Organics (e.g., food waste)		10
Miscellaneous		7
TOTAL		100

These percentages represent the average for all wastes produced. However, waste composition in each generator category can vary significantly from these averages. For example, office and classroom wastes are roughly 80 percent paper, 65 percent of which is recyclable. Residence halls and food service facilities produce wastes that are approximately 50 percent paper and 15 percent organics.

Typical Collection Practices--

Collection procedures vary by the type of activity taking place within a building. Three types of activities were identified as having different collection procedures: (1) office/classroom, (2) residential hall, and (3) food service.

All wastes from these activities, except from food service, initially are deposited in waste baskets. Food waste in the food service area typically is discarded into the sewer system via a garbage disposal. The other discards are put into waste containers. The custodial staff collects the waste in the baskets and transfers it to a central storage area. Transfer of residential hall waste from student rooms to an incinerator was common prior to the advent of clean air legislation. In a few locations, this waste still is incinerated. The collected waste is stored in a central area prior to removal from the building. The material usually is stored in refuse bins or compactors, depending on the quantity of waste generated in the building. Frequency of refuse removal varies also depending on the quantities of waste generated, as well as on the storage container used.

Typical Disposal Practices--

No quantitative studies have been done on how universities dipose of their wastes. Indications are that the majority of the wastes disposed by universities is landfilled. Two other disposal options used by universities are incineration and garbage maceration.

MULTI-UNIT RESIDENTIAL WASTE STREAMS

Garden or Low-Rise Apartments

Waste Stream Characteristics--

The quantity and composition of the solid waste generated at a garden or low-rise apartment is affected by several variables:

- Number of apartment units
- Number and size of families
- Average age of tenants
- Income level

No published studies on the characteristics of solid waste specifically from garden or low-rise apartments were found. Information was collected through telephone surveys in the Washington, D.C., New Brunswick, New Jersey and Milwaukee, Wisconsin areas, (Personal communications. Ted Meyer, Waste Management, Inc., Milwaukee, Wisconsin. May 15, 1978; Gene Conlon, Jersey

Sanitation, New Brunswick, New Jersey. May 16, 1978; and S. Johnson, Mt. Vernon Square Apartments, Alexandria, Virginia. May 25, 1978). The survey indicated that the daily average quantity of solid waste generated per person in a garden or low-rise apartment is essentially the same as the average residential waste generation rate. The major difference is the quantity of yard waste generated. The waste managers contacted felt that per capita yard waste was lower for residents in garden apartments than single-family home dwellers. An EPA staff study estimated an average generation of 3.5 pounds per person per day of residential and commercial waste in 1976 (20). About 0.8 pounds per person per day of this can be attributed to commercial sources; thus residential generation rate was 2.7 pounds per person per day. An adjustment factor of 0.2 was subtracted from the national average residential generation rate to account for the decrease in yard wastes. The generation rate for garden apartments was assumed to be 2.5 pounds per person per day.

The composition of the solid waste generated in garden apartments was estimated to correspond to the composition of average residential waste, except for yard wastes. The estimated composition was derived from EPA data and the information survey. The estimated composition of waste from garden apartments is:

Type of Material	Percent of Total (Weight Basis)
Paper	35
Glass	12
Metal	10
Plastic	5
Organics (e.g., food and yard wastes)	27
Miscellaneous	11
TOTAL	100

Typical Collection Practices--

The solid waste generated in garden apartments is stored initially in conventional in-house containers. In apartments equipped with garbage disposal units, food waste is disposed into the sewerage system. Tenants are usually required to transport the waste to an intermediate storage container. This container was found to range in size from a 30-gallon container to a multi-cubic yard dumpster. One complex surveyed used another approach.

Tenants are given plastic bags in which to store their wastes. The bags may be set outside the front door of the apartment any weekday morning for collection and the ground crew takes the bags to the curb for collection by the apartment's ground crew.

Another source of solid waste is the refuse that results from maintaining the grounds and building. These wastes are stored by the apartment management and collected at the same time as the tenant's waste.

The majority of garden apartments surveyed were serviced by private haulers on contract with the apartment complex. Some larger and older complexes provide their own refuse collection service.

Typical Disposal Practices--

No quantitative studies have been done on how garden apartments dispose of their wastes. Landfill, however, appears to be the common method of disposal. At one time, on-site incineration of waste in large garden apartment complexes was common. This practice has been phased-out with the advent of stricter air pollution control laws.

Trailer Parks

Waste Stream Characteristics--

The quantity and composition of the solid waste generated at a trailer park is affected by several variables. The significant variables are:

- Number of trailers
- Family size
- Average age of residents
- Income level
- Number and type of park services and community buildings

No published studies on the characteristics of solid wastes from trailer parks were found. The characteristics of solid waste from trailer parks were investigated through telephone surveys in the Washington, D.C. and Milwaukee, Wisconsin areas, (Personal communications. Ted Meyer, Waste Management, Inc., Milwaukee, Wisconsin. May 15, 1978; and M. Waples, Mobile Home Estates, Fairfax, Virginia. May 25, 1978). The survey indicated that the daily average quantity of solid waste generated per person in a trailer park is essentially identical to the average residential waste generation rate. The EPA average residential waste generation rate of 2.7 pounds per person per day was used for trailer parks. The major difference between average residential waste and refuse from trailer parks is composition. Nonfood-nondurable product waste from trailer parks is identical to waste from other types of residences with comparable demographic characteristics. The difference is the larger proportion of food waste in refuse from trailer parks. The general lack of garbage disposal units is trailers is the reason for the high food waste level. The other difference is the lower level of durable goods discards, in particular white goods. Home appliances are discarded, but are smaller, on the average, than those used in the typical residence.

The composition of the solid waste generated in the average trailer park is estimated to closely correspond to the composition of average residential waste. This estimate was based on EPA data and the information survey. The estimated composition of solid waste from trailer parks is:

Type of Material	Percent of Total (Weight Basis)
Paper	34
Glass	12
Metal	12
Plastics	5
Organics (e.g., food and yard wastes)	25
Miscellaneous	12
TOTAL	100

Typical Collection Practices--

The solid waste generated in trailer parks is stored initially in conventional in-residence containers. If intermediate storage prior to collection is necessary, a trailer resident typically has two options: transfer of the waste to 30-gallon containers outside the trailer or transfer of the waste to a dumpster. In each of the trailer parks surveyed, the residents were responsible for placing their waste at curbside on collection days. The frequency of collection varies from once to twice a week. The collection rate typically depends on the trailer park management, who arranges collection service for the entire park.

Typical Disposal Practices--

No quantitative studies have been done on how trailer parks dispose of their wastes. Indications are that landfill is the predominate method of disposal.

OFFICE COMPLEX WASTE STREAMS

Office Buildings

Waste Stream Characteristics--

A number of studies have been conducted to characterize the waste stream from office buildings. Many variables affect the quantity and thus variability results from a number of factors:

- Type of office function
- Presence of a cafeteria

EPA studies indicate that bank and insurance office operations, which generate large quantities of computer paper and forms, can produce as much as 2.3 lbs of solid waste per person per day (exclusive of cafeteria wastes) of which 93 percent may be paper (21). EPA and SCS Engineers studies have shown that the average office worker generates 1.5 pounds of waste per day of which 1.3 pounds is paper and 0.5 pounds is recoverable paper. These figures are variable depending on the type of office functions performed, the presence of a computer or print shop and transfer of paper into and out of the building. The percentages of other waste stream materials such as metal and glass are not well-documented. However, an SCS study identified a "typical" office wastestream from a survey of 15 office and/or academic buildings as follows:

Solid Waste Component	Percent by Weight
Paper	87
Metal	7
Glass	1
Plastic	1
Miscellaneous	4
TOTAL	100

The extent to which food wastes enter the waste stream is dependent upon the manner in which office employees are provided meals within a building. In buildings with no cafeteria or nearby carryout restaurants, the percentage of food waste entering the waste stream is not high. In buildings where the cafeteria functions independent of the office building operations, separate collection of garbage from solid wastes is usually the case; whereas in office buildings incorporating the provision of food services to employees, solid waste collection from the cafeteria and office areas may be under the control of the same custodial staff. Given these variables, the percentage of food wastes entering the office wastestreams must be calculated on an individual basis.

Typical Collection Practices--

Collection methods utilized within office areas are directly related to building size, configuration and management operations. Large industrial complexes with associated business management office centers will often employ custodians as part of their personnel allottment, whereas high-rise complexes may employ custodial help or contract for the services. Whatever the arrangements, basic collection techniques usually involve the utilization of custodial night crews to collect solid waste. Wheeled hampers usually are used to collect wastes from individual waste baskets in each office area within the building. Full hampers are taken (via elevator) to a basement loading dock area where they are emptied into dumpsters or stationary compactors.

Typical Disposal Practices--

Solid waste disposal services are almost always contracted through independent companies. The majority of waste is disposed of by landfilling. A number of office buildings are implementing source separation programs to recover high grade paper.

SMALL CITY WASTE STREAMS

Waste Stream Characteristics--

Small cities are defined here as cities generating up to 100 tons per day of residential and commercial refuse. The solid waste characteristics of municipalities are extremely difficult to define bacause there are a number of variables which affect quantity and composition:

- Geographic location/climate
- Season
- Type of industrial activities
- Type of commercial activities
- Socio-economic characteristics of population
- Type and frequency of solid waste collection services
- State of the economy

Numerous studies have been done by the Environmental Protection Agency which attempt to estimate average solid waste generation rates for residential and commercial usage. Figures from 1976 indicate an average per capita generation rate of approximately 3.5 pounds per person per day (20). Typical waste composition figures are (23):

Material		Percent of Total (Weight Basis)
Paper		32
Glass		10
Metals		9
Ferrous	8	
Aluminum	1	
Plastics		3
Food Waste		17
Yard Waste		19
Miscellaneous (e.g., rubber, wood)		10
TOTAL		100

Typical Collection Practices--

Municipal collection practices throughout the country are well documented. A variety of alternatives for collection exist: private, public, a combination of public and private, or homeowner transport/collection of wastes. Recent trends have indicated an increase in municipalities which choose private collection of municipal wastes. Some small cities have private collection of certain segments of the waste stream, generally inorganics such as glass and metals, as well as paper, with collection or organics by municipal crews. However, this practice is decreasing. A number of small cities do not have any municipal collection of wastes and residents are expected to haul their own wastes to the disposal site. These cities are generally quite small and located in rural areas. As in large cities, collection of commercial waste is sometimes provided by the municipality but is usually contracted with a private hauler.

Typical Disposal Practices--

The majority of small cities landfill their wastes, but other disposal options are not uncommon. These include incineration, modular incineration, and source separation.

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SECTION III

TECHNOLOGY SYSTEM EVALUATION

The current state-of-the-art approaches to resource recovery applicable to the parameters of this study are discussed and evaluated in this section. Unit processes (components) considered technologically proven at the 100 TPD level or less are assembled into resource recovery systems applicable to the waste generators. Operational and technical aspects of each system are discussed and a cost analysis developed which reports net disposal cost per ton of input.

The various systems that have applicability to small waste generators can be divided into three types:

- Direct Recovery of Materials
- Indirect Recovery of Materials
- Recovery of Energy With or Without Materials Recovery.

These types of systems can produce different kinds of material and energy outputs including the following:

Materials Recovery		Energy Recovery	
Direct	Indirect	Direct	Indirect
Glass	Compost	Steam	RDF
Steel	Yeast	Hot Air	Pyrolytic Fuel
Paper		Hot Water	Methane
Aluminum			Alcohol

Direct recovery of materials is the separation of glass, aluminum, steel, paper and/or other materials for recycling. Systems separating these materials are in use on the municipal or pilot plant level, but commercial systems are usually well above 100 TPD in capacity. Separated materials may or may not go through some intermediate processing such as crushing or flattening.

Indirect recovery of materials and energy involves most of the direct recovery processes plus that of an additional transformation step. Economics are dependent on suitable markets and their proximity to the waste generator. Larger scale versions of indirect recovery operations are less numerous than direct recovery operations.

Direct energy recovery is the most promising type of system suitable for small waste generators. Equipment is designed and marketed expressly for such applications, and numerous facilities up to 100 TPD are currently in operation. The greatest advantage of engery recovery is easy marketability. The steam, hot water, hot air, or other energy produced, generally, can be used either internally or at nearby locations. The close proximity of the user and producer of energy makes the transportation and storage costs of this recovery option relatively cheap vis-a-vis other recovery options. There are two potential problems with direct energy recovery. First, the ability of modular incinerators to consistently meet air quality standards has yet to be proven. In addition, siting an incinerator could be a serious problem for some small waste generators.

DEFINITIONS AND BASIC ASSUMPTIONS

Proven Technology

For the purpose of this study, components of resource recovery systems are considered technologically proven if, at 100 TPD or less, the component has:

- Operated commercially for at least one year
- Produced the desired product in a form which has been sold at the projected value

This definition eliminates components in pilot scale or shake-down tests. Likewise, it eliminates those components generating a product that is not currently marketable.

Assumptions

The cost analyses require several assumptions about labor and equipment costs and the revenues available for the recovered materials or energy. The systems will later be evaluated comparatively to determine those most feasible for use by specific types of waste generators based on cost and other factors. Thus, to the degree possible, uniform and realistic cost assumptions will be used for all systems' cost analyses. Unless otherwise noted on the cost analyses tables, the following are assumed:

- Equipment and facilities will be amortized over their useful lives (5, 15, or 20 years as indicated) at 8 percent interest

- Small-scale systems will have an input capacity of 100 TPD

- System operations of five days per week and eight hours per day will be adequate to process the 500 tons of refuse delivered each week.

- Cost to haul to landfill and disposal was assumed to be $7 per ton

SMALL-SCALE SYSTEMS

Components

Various components of resource recovery systems for a 100 TPD operation are available, though some have yet to be proven in commercial operation. The components include:

acid hydrolysis conversion units
air classifiers
aluminum magnets
composting equipment
froth flotation units
methane digestors
modular incinerators
pyrolytic units
shredders
trommel screens
magnetic separators

The components have been combined into several system configurations, though not necessarily in a commercial operating basis or on a small scale. These systems have yielded various energy and material products of differing degrees of marketability. Detailed descriptions of the components are included in Appendix D.

Several components were eliminated based on technical criteria. These are listed below along with the reasons for elimination:

- Acid hydrolysis conversion units - currently in the experimental and pilot plant stages (1).

- Aluminum magnets - an aluminum magnet is in use in Ames, Iowa. However, due to the extremely small amount of aluminum in the waste stream (only 0.8 tons have been recovered in the past year), it is not possible to judge the magnet's effectiveness in more representative situations. Other aluminum magnets have been installed at Milwaukee, Wisconsin (1978), New Orleans, Louisana (1978), and Baltimore County, Maryland (1978), but are still in the shakedown phase. Consequently, aluminum magnets do not meet the first criterion-commercial operation for more than one year, and thus were rejected. All of these facilities were designed for more than 100 TPD operations, (Personal communications. Joseph Duchett, National Center for Resource Recovery, Washington, D.C. July 7 1978; and Stephen Howard, Environmental Protection Agency, Washington, D.C. July 7 1978).

- Froth flotation units - a unit currently is in shakedown in New Orleans. The recovery system under construction in Bridgeport, Connecticut will include a froth flotation unit. The U.S. Bureau of Mines is testing glass recovery processes at its Edmonston, Maryland facility.

  Recovery rates for the glass entering the flotation unit are estimated to be 90 percent. A significant quantity of glass in the original waste stream; however, may be lost in the early processing stages. The purity of the recovered glass has been estimated to be as high as 99 percent. Even at this level of purity, the glass may be unable to meet container industry specifications, (Personal communications. Joseph Duchett, National Center for Resource Recovery, Washington, D.C. July 7 1978). The primary contaminates are ceramics and stones, which have a higher melting point than glass. These materials will foul a production run if they are in the feedstock. All the glass in the run must then be discarded. Consequently, container companies do not want to purchase cullet containing such contaminates.

  Froth flotation units were rejected on both criterion.

- Methane digestors - this technology is quite old and is well demonstrated at wastewater treatment plants. However, the input feed in these plants is sewage sludge. A pilot plant to process 50-100 tons per day of solid waste mixed with sewage sludge recently has been constructed in Pompano Beach, Florida. The purpose of this plant is to test the technical and economic feasibility of bioconversion of solid waste, (Personal communication. Peter Ware, Waste Management, Inc., Oak Brook, Illinois. July 12 1978; and Donald Walter, Department of Energy, Washington, D.C. July 12 1978). Consequently, this process does not meet either criterion for acceptability.

- Pyrolytic units - two commercial-scale units have been built - Baltimore, Maryland (1000 TPD) and San Diego, California (200 TPD). Neither system, however, is in operation. There have been problems in the scale-up from demonstration units. The Union Carbide Corporation has been operating a pyrolysis system in South Charleston, West Virginia since 1974 (2). This plant is a demonstration unit. A small pyrolytic system is operating at an industrial site in Arkansas. It is still in the shake-down phase (3). Due to failure to meet the one year of commercial scale operation criterion, pyrolysis was eliminated from further consideration.

System Evaluated

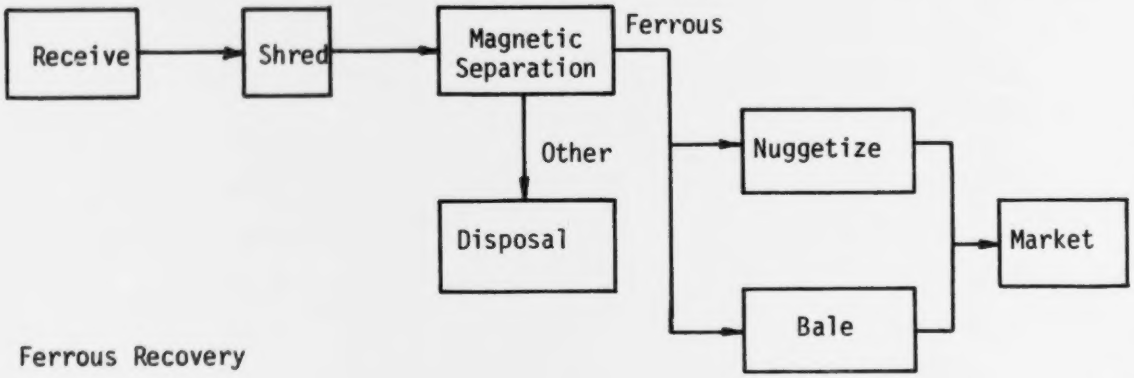
The remaining components were combined into six small-scale system for further analysis. Flow diagrams of these systems are shown in Figures 1 through 3.

- Ferrous Recovery
- Compost Preparation
- Compost Preparation with Ferrous Recovery
- RDF Preparation with Ferrous Recovery
- Incineration with Heat Recovery
- Incineration with Heat and Ferrous Recovery

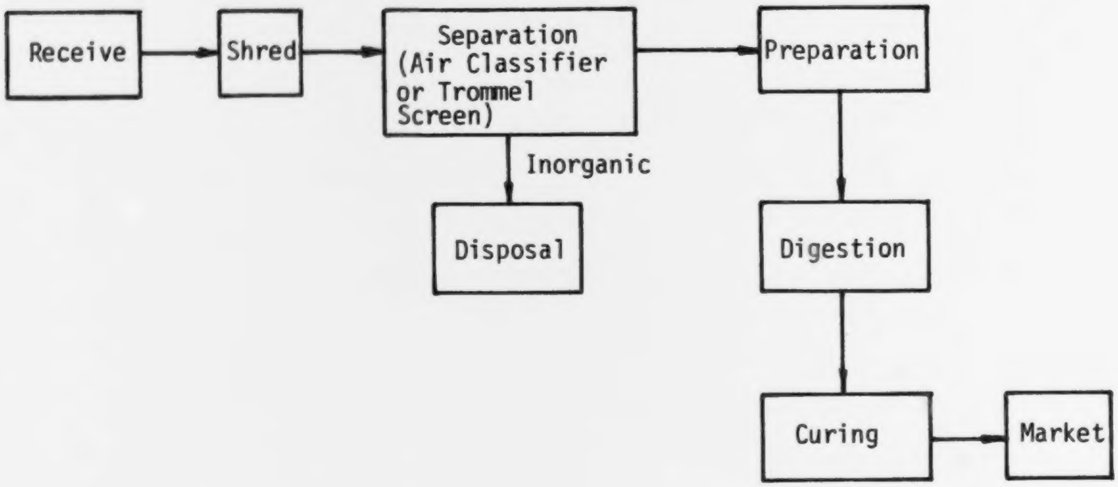
Ferrous Recovery

This system recovers only ferrous material, Figure 1. Solid waste is received and fed into the shredder. The shredded waste passes through the magnetic separator which diverts the magnetic fraction (mostly cans) to a baler or nuggetizer for compressing into a marketable product. Although not detailed in the flow diagram, transportation to the customer usually is required. Scrap metal which is delivered to a buyer brings a higher price than that which is picked up (4). The non-magnetic portion of the waste stream is landfilled without further processing.

The net cost per ton for a ferrous recovery system at 100 TPD of input waste is $15.38, Table 8. The revenue from the recovered ferrous was determined to be $1.08 per input ton of


Receive
Shred
Magnetic Separation
Ferrous
Other
Disposal
Nuggetize
Bale
Market

Ferrous Recovery


Receive
Shred
Separation (Air Classifier or Trommel Screen)
Preparation
Inorganic
Disposal
Digestion
Curing
Market

Compost Preparation

Figure 1 Process Flow Diagrams-
Ferrous Recovery and Compost Preparation

TABLE 8. COST ANALYSIS FOR A REPRESENTATIVE FERROUS RECOVERY[1] SYSTEM (100 TPD)

			Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)						
Shredder, including dust control and Bag House, complete in place			$400	5	0.250	$100
Magnetic Separator			30	5	0.250	8
Baler			30	5	0.250	8
Auxiliary Equipment			50	5	0.250	13
	Small Front-End Loader	40				
	Office Furniture, Refuse Bins	10				
Construction & land			392	20	0.101	39
	Building: $9500\ \text{ft}^2$ @ $\$30/\text{ft}^2$	285				
	Site Development: 20% of bldg	57				
	Land: 5 acres @ $10,000/acre	50				
	TOTAL		$802			$168
OPERATING COSTS ($1,000)						
Labor;[2]	2 operators @ $24 1 supervisor @ $16					40
Supplies:	3% of labor & maint.					2
Energy:[3]	Stationary equipment:		$ 12.0			
	Mobile loader		3.2			
	Lighting		0.7			
	Building heat		1.3			17
Maint.:	3% of total capital costs					24
Misc.:	(taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					8
	TOTAL					$ 91
TOTAL ANNUAL SYSTEM COSTS ($1,000)						$259
COST/REVENUES PER TON ($/ton)						
	System Cost					$ 9.96
	System Revenue[4]					1.08
	Net System					8.88
	Landfill[5]					6.50
	Total Net					$ 15.36

TABLE 8 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Operator wage rates is $5.80 per hour which includes fringe benefits of 15 percent

Supervisor wage rate is $7.80 per hour, including fringe benefits.

[3] Energy:

Stationary Equipment - operation conditions are:

• Electric Power Consumption:	18kwh/ton
- Cost	$1,000/month

Mobile Equipment - oeration conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[4] Revenue Factors:

• Percent ferrous in wastestream	8%
• Recovery rate	90%
• Market value	$15/ton FOB the receiving site

[5] Cost Factors:

• Weight reduction	7.2%
• Cost to haul to landfill and disposal	$7/ton

refuse. This was based on a ferrous fraction in the waste stream of 8 percent. The recovery rate was assumed to be 90 percent of incoming ferrous.

Compost Preparation

Compost is a humus-like material which can enhance the quality of soil. It improves soil quality by increasing the soil's ability to retain moisture. Compost, however, lacks the constituents to be classified a fertilizer.

Solid waste passes from the receiving area to the primary shredder where it is size-reduced to approximately 2 inches, Figure 1. The material is then sent to a separation process, which could be either air classification or trommeling, resulting in organic (light) and inorganic (heavy) wastestreams. Inorganic material is usually disposed of in a landfill. About 50 percent of the wastestream, called the organic fraction, passes to the composting preparation stage. The moisture content is corrected, with sewage sludge often being blended into the mixture. The prepared material is digested in aerated containers or placed in open windrows. No windrow compost operations using solid waste as a feed stock are in operation in this country. Several operations have been attempted, but they were not economic. After a period of time, which can vary from days to months, the compost is transferred to a storage area for curing -- actually an extension of the digestion process. The compost is then ready for use. For some applications, further processing, such as secondary shredding and additional screening, is necessary.

Although technically proven, commercial composting operations have never been cost-effective in the United States. A facility representative of the system depicted in Figure 1 is in operation at Altoona, Pennsylvania. This plant, which is operated by a private firm, processes 50 TPD of raw refuse.

The net cost per ton of input waste at 100 TPD was determined to be $26.70, Table 9. As previously mentioned, the major problem with composting systems in the past have been the low marketability of the product. For the cost analysis it has been assumed that the value of compost is derived from its utility as a topsoil substitute. Other basic assumptions are shown in the table.

Compost Preparation With Ferrous Recovery

Composting produces a material which can be used to enhance the productivity of land, as was described under the previous heading. In addition, this system recovers the ferrous fraction of solid waste.

This system is the same as the one for just composting except for the addition of a ferrous recovery subsystem, Figure 2.

TABLE 9. COST ANALYSIS FOR A REPRESENTATIVE AEROBIC COMPOST PLANT[1] (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Shredder, including dust control		$350	5	0.250	$ 88
Air Classifier and Bag House		250	5	0.250	63
Compost Equipment		980	5	0.250	245
Auxiliary Equipment		50	5	0.250	13
Small Front-End Loader	40				
Office Furniture, Refuse Bins	10				
Construction & land		464	20	0.101	46
Building: 11,500 ft^2 @ \$30/ft^2	345				
Site Development: 20% of bldg	69				
Land: 5 acres @ \$10,000 acre	50				
TOTAL		$2094			$455
OPERATING COSTS ($1,000)					
Labor:[2] 4 operators @ \$48 1 supervisor @ \$16					64
Supplies: 3% of labor & maint.					4
Energy:[3] Stationary equipment:	\$ 93.6				
Mobile equipment	3.2				
Lighting	0.9				
Building heat	1.6				99
Maint.: 3% of total capital cost					63
Misc.: (taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					21
TOTAL					$251
TOTAL ANNUAL SYSTEM COSTS ($1,000)					$706
COSTS/REVENUES PER TON ($/ton)					
System Cost					27.15
System Revenue[4]					3.11
Net System					24.04
Landfill[5]					2.66
Total Net					$ 26.70

TABLE 9 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Operator wage rate is $5.80 per hour which includes fringe benefits of 15 percent.

Supervisor wage rate is $7.80 per hour, including fringe benefits.

[3] Energy:

Stationary Equipment - operation conditions are:

• Electric Power Consumption	45 kwh/ton
- Cost	$2,390/month
• Natural Gas Consumption	9 therms/ton
- Cost	$0.2776/therm

Mobile Equipment - operation conditions are:

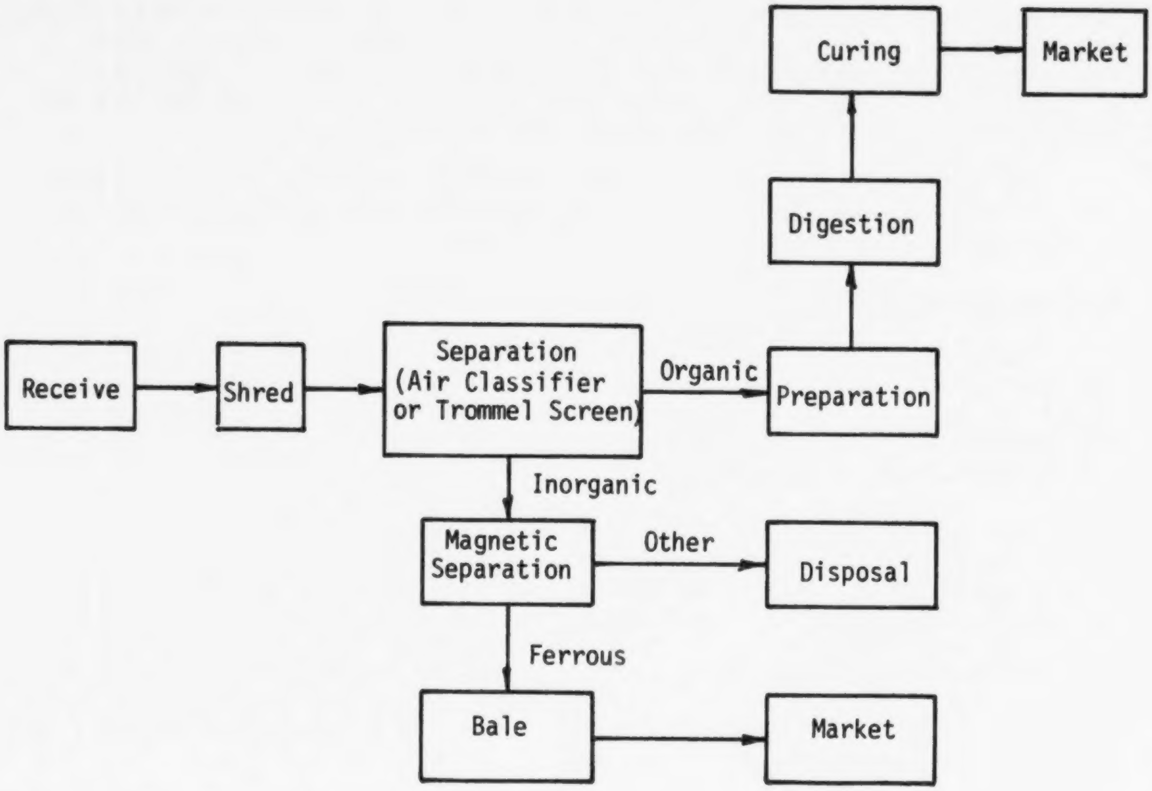
• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[4] Revenue Factors:

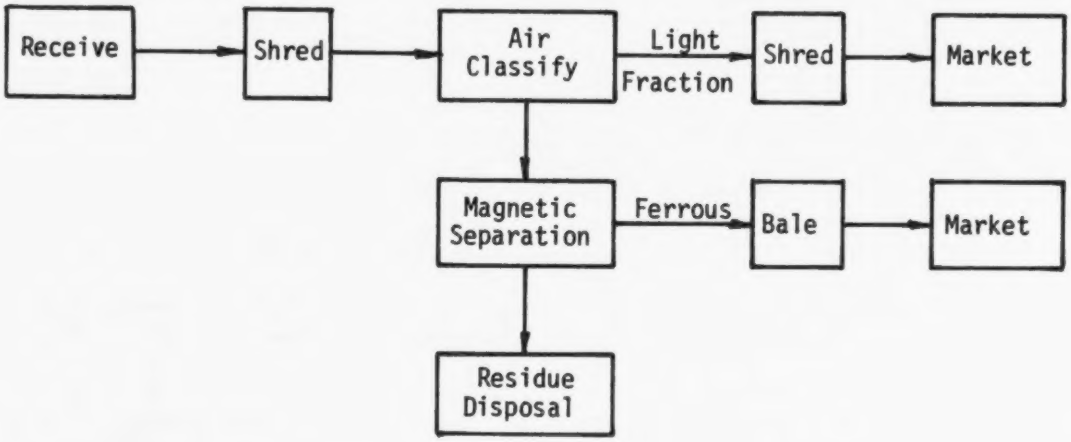
• Percent compostables in wastestream	69%
• Recovery rate	90%
• Market value	$5.00/ton FOB the recovery site

[5] Cost Factors:

• Weight reduction	62%
• Cost to haul to landfill and disposal	$7/ton


Curing
Market
Digestion
Receive
Shred
Separation (Air Classifier or Trommel Screen)
Organic
Preparation
Inorganic
Magnetic Separation
Other
Disposal
Ferrous
Bale
Market

Compost Preparation with Ferrous Recovery


Receive
Shred
Air Classify
Light Fraction
Shred
Market
Magnetic Separation
Ferrous
Bale
Market
Residue Disposal

RDF Preparation with Ferrous Recovery

Figure 2 Process Flow Diagrams-
Compost Preparation with Ferrous Recovery and RDF
Preparation with Ferrous Recovery

Ferrous is recovered following separation of the waste into light and heavy fractions. The heavy fraction, which contains the ferrous, is processed through a magnetic separator. The recovered ferrous would be processed further, either by baling or nuggetizing to prepare the metal for market.

At 100 TPD, the net cost per ton of input is $26.05, Table 10. The value of the compost and ferrous was set at $3.11 and $1.08 respectively per ton of input waste.

Refuse-Derived Fuel (RDF)

Refuse-derived fuel is an energy source produced from the combustible fraction of solid waste. There are three basic types of RDF which can be produced: fluff, dust and densified. The production of these three types varies, as does the burn characteristics and markets.

The basic system for production of fluff RDF involves: (1) shredding, (2) separation of the combustible and noncombustible fraction of waste by air classification, and (3) secondary shredding, Figure 2. The production of dust or densified RDF requires additonal steps. Neither of these two types of RDF have been included because of the lack of commercial-scale experience. The three RDF systems in operation (Ames, Iowa - 200 TPD, Chicago, Illinois - 1000 TPD, and Milwaukee, Wisconsin - 1600 TPD) produce fluff RDF.

Market acceptance of RDF appears uncertain at the present time. Users of RDF must modify storage, handling and combustion practices to burn the material in existing or modified boilers. Similarly, the uncertainty of future supply and quality control makes boiler owners wary of commitments to this type of fuel.

Current prices for RDF vary as noted below:

- Ames, Iowa reported a 1977 average price for RDF of $9.41 per ton, (Personal communication. Robert Bartolotta, City of Ames, Ames, Iowa. July 26, 1978).
- Chicago sold RDF for $4.20 per ton, (Personal communication. Emil Nigro, City of Chicago, Illinois. July 26, 1978).
- Milwaukee is getting about 50 percent of the energy equivalent price of coal of about $12 per ton based on the following, (Personal communication. Rosanne Schwaderer, Coal Week Magazine, Washington, D.C. July 24, 1978):

TABLE 10. COST ANALYSIS FOR A REPRESENTATIVE AEROBIC COMPOST PLANT WITH FERROUS RECOVERY[1] (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Shredder, including dust control		\$350	5	0.250	\$ 88
Air Classifier and Bag House		250	5	0.250	63
Magnetic Separator		30	5	0.250	8
Baler		30	5	0.250	8
Compost Equipment		980	5	0.250	245
Auxiliary Equipment		50	5	0.250	13
Small Front-End Loader	40				
Office Furniture, Refuse Bins	10				
Construction & land		474	20	0.101	47
Building: 11,750 ft^2 @ \$30/ft^2	353				
Site Development: 20% of bldg	71				
Land: 5 acres @ \$10,000/acre	50				
TOTAL		\$2164			\$ 472
OPERATING COSTS ($1,000)					
Labor:[2] 4 operators @ \$48 1 supervisor @ \$16					64
Supplies: 3% of labor & maint.					
Energy:[3] Stationary equipment		96.7			
Mobile equipment		3.2			
Light		1.0			
Building heat		1.7			103
Maint.: 3% of total capital cost					65
Misc.: (taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					22
TOTAL					\$ 258
TOTAL ANNUAL SYSTEM COSTS ($1,000)					**\$730**
COSTS/REVENUES PER TON ($/ton)					
System Cost					28.08
System Revenue[4]					4.19
Net System					23.89
Landfill[5]					2.16
Total Net					\$ 26.05

TABLE 10 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Operator wage rate is $5.80 per hour which includes fringe benefits of 15 percent.

Supervisor wage rate is $7.80 per hour, including fringe benefits.

[3] Energy:

Stationary equipment - operation conditions are:

• Electric Power Consumption	50 kwh/ton
- Cost	$2,640/month
• Natural Gas Consumption	9 therms/ton
- Cost	$0.2776/therm

Mobile Equipment - operation conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[4] Revenue Factors:

• Compost ($3.11/input ton)	
- Percent compostables in wastestream	69%
- Recovery rate	90%
- Market value	$5.00/ton FOB the recovery site
• Ferrous ($1.08/input ton)	
- Percent ferrous in wastestream	8%
- Recovery rate	90%
- Market value	$15.00/ton FOB the recovery site

[5] Cost Factors:

• Compost: Weight reduction	62%
• Ferrous: Weight reduction	72%
• Cost to haul to landfill and disposal	$7/ton

- Energy content of RDF ranges from 6,500 to 8,000 BTU per pound

- Coal with 1.1 percent sulfur, 12.8 percent ash, and 12,000 BTU per pound costs $24 per ton

Taking the above into consideration, and considering the small quantities of RDF produced at a 100 TPD plant, it was assumed that the RDF would command a price of $6.00 per ton FOB the recovery facility. The net cost per input ton at a 100 TPD facility would be $13.61, Table 11.

Modular Incinerator With Heat Recovery

Modular incinerators are now available with the ability to recover energy in the form of steam, hot water, and hot air. The incinerators are designed for simplicity of operation, Figure 3. Mixed refuse is dumped onto a tipping floor and then moved directly into burner charging hoppers using small tractors. The only processing normally done is the removal of bulky items. The hot gases generated can then be passed through a heat exchanger or boiler to heat water or produce steam. Residue from the combustion process is automatically and continuously removed from the newer, larger units. Thus, 24-hour operation is possible. However, older designs and some current units require a cool-down period each day, after which ashes are removed mechanically or manually before the unit is reignited.

Air pollution is a concern with any combustion process. Entrainment of particles is minimized in modular incinerators through use of the starved air concept. Afterburners in the secondary chamber provide additonal control in the reduction of particulate emissions. Gaseous emissions (e.g., nitrous oxides and metalized salts) also are controlled because of the low bed temperature in the combustion chamber. Even so, the data are incomplete on the ability of these incinerators to consistently meet air quality standards. Tests are being conducted to determine the stack emissions from these units. Stricter regulations at the Federal level may necessitate additional controls in the future, even if modular incinerators are able to meet local standards currently.

Individual heat recovery modular incinerators are available with capacities ranging from 1 to 50 TPD. Units are often installed in groups of two, three, or four (or more) to provide adequate capacity and back-up. Units above 3 TPD may be designed for 24-hour operation.

The incinerator unit typically is located close to the user of the energy. The shorter the distance between the two, the lower the transmission loss and the higher the economic benefit for the incinerator operator. Steam may be transmitted in ex-

TABLE 11. COST ANALYSIS FOR A REPRESENTATIVE REFUSE-DERIVED FUEL (RDF) AND FERROUS RECOVERY[1] SYSTEM (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Shredders (2), including dust control		$600	5	0.250	$150
Air Classifier and Bag House		250	5	0.250	63
Magnetic Separater		30	5	0.250	8
Baler		30	5	0.250	8
Auxiliary Equipment		50	5	0.250	13
Small Front-End Loader	40				
Office Furniture, Refuse Bins	10				
Construction & land		464	20	0.101	46
Building: 11,500 ft^2 @ $30/$ft^2$	345				
Site Development: 20% of bldg.	69				
Land: 5 acres @ $10,000/acre	50				
TOTAL		$1424			$288
OPERATING COSTS ($1,000)					
Labor:[2] 3 operators @ $36					
1 supervisor @ $16					52
Supplies: 3% of labor & maint.					3
Energy:[3] Stationary equipment		22.7			
Mobile loader		3.2			
Lighting		0.9			
Building heat		1.6			28
Maint.: 3% of total capital cost					43
Misc.: (taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					14
TOTAL					$140
TOTAL ANNUAL SYSTEM COSTS ($1,000)					$428
COSTS/REVENUES PER TON ($/ton)					
System Cost					16.46
System Revenue[4]					4.32
Net System					12.14
Landfill[5]					1.47
Total Net					$ 13.61

TABLE 11 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Operator wage rate is $5.80 per hour which includes fringe benefits of 15 percent.

Supervisor wage rate is $7.50 per hour, including fringe benefits

[3] Energy:

Stationary Equipment - operation conditions are:

• Electric Power Consumption	35 kwh/ton
- Cost	$1,890/month

Mobile Equipment - operation conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[4] Revenue Factors:

• RDF ($3.83/input ton)

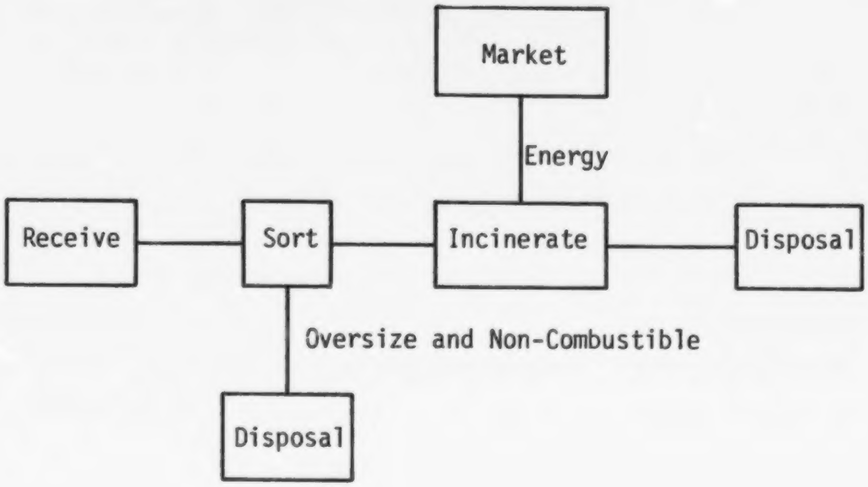
- Percent combustibles in wastestream	80%
- Recovery rate	90%
- Market value	$6.00/ton FOB the recovery site

• Ferrous ($1.08/input ton)

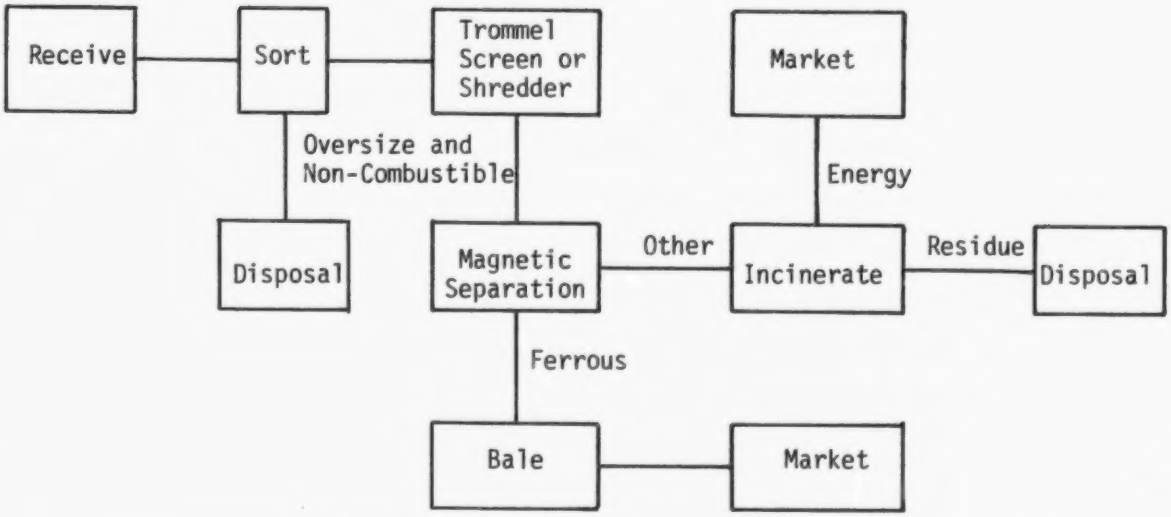
- Percent ferrous in wastestream	8%
- Recovery rate	90%
- Market value	$15.00/ton FOB the recovery site

[5] Cost Factors:

• RDF: Weight Reduction	72.0%
• Ferrous: Weight Reduction	7.2%
• Cost to haul to landfill and disposal	$7/ton


Market
Energy
Receive
Sort
Incinerate
Disposal
Oversize and Non-Combustible
Disposal

Incineration with Energy Recovery


Receive
Sort
Trommel Screen or Shredder
Market
Oversize and Non-Combustible
Energy
Disposal
Magnetic Separation
Other
Incinerate
Residue
Disposal
Ferrous
Bale
Market

Incineration with Energy Recovery and Ferrous Recovery

Figure 3 Process Flow Diagrams-
Incineration with Energy Recovery
Incineration with Energy Recovery and Ferrous Recovery

cess of 1.5 miles, if constraints preclude operation of the incinerator closer to the energy user. Probable uses for the recovered energy are industrial processes, and a connection with an existing steam loop, augmenting the steam generated in a central boiler. These situations may be present in hospitals, prisons, airports, office buildings, and garden apartment complexes.

Depending on local regulations, the operation of these units may not require the presence of a full-time stationary engineer. Successful operation of an incinerator does require the presence of trained personnel. Otherwise, the performance of the system probably will be less than desired.

A net cost of $11.68 per ton of input refuse at 100 TPD was calculated for this system, Table 12. The value of the energy recovered from from the incinerated waste was determined to be just over $8 per input ton.

Modular Incineration With Heat and Ferrous Recovery

It would be possible to develop a small-scale system combining ferrous recovery with modular incinerators. The incinerators are designed to accept unshredded refuse. Although no tests have been done, it is possible that shredded waste could be burned in this type of incinerator without adverse affects. Ferrous recovery could decrease maintenance costs. The charging hoppers and rams, material transport mechanisms, refractory, and ash handling systems might require less maintenance if ferrous is removed from the waste to be incinerated. The ferrous would be recovered following some processing (e.g., shredding), Figure 3. The recovery technique would be magnetic separation. The recovered metal would be processed for marketing either by baling or nuggetizing..

Ferrous metals also can be recovered from the incinerator residue. The market for incinerated ferrous, however, is extremely poor at the present time, (Personal communication. Howard Ness, National Association of Recycling Industries, New York, New York. July 18, 1978). Therefore, this approach to ferrous recovery was rejected.

A net cost of $11.95 per ton of input waste at 100 TPD was determined for this system, Table 13. The revenue from the steam and ferrous is $8.08 and $1.08 respectively per input ton.

LOW TECHNOLOGY SYSTEMS

Source Separation

The materials commonly recovered by a source separation system are:

TABLE 12. COST ANALYSIS FOR A REPRESENTATIVE MODULAR INCINERATOR WITH ENERGY RECOVERY[1] (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Incinerator and boiler, complete in place[2]		$1800	15	0.117	$210
Auxiliary Equipment		50	5	0.250	13
Small Front-End Loader	40				
Office Furniture, Refuse Bins	10				
Construction & land		396	20	0.101	40
Building: 9500 ft^2 @ $\$30/\text{ft}^2$	288				
Site Development: 20% of bldg.	58				
Land: 5 acres @ $10,000/acre	50				
TOTAL		$2196			$263
OPERATING COSTS ($1,000)					
Labor:[3] 4 operators @ $48					
1 supervisor @ $16					64
Supplies: 3% of labor & maint.					3
Energy:[4] Supplemental fuel		36.0			
Mobile loader		3.2			
Lighting		0.7			
Heat building		1.3			41
Maint.: 3% of total capital costs					66
Misc.: (taxes, licenses, insurance, adminstrative and management costs) 1% of total initial capital costs					22
TOTAL					$196
TOTAL ANNUAL SYSTEM COSTS ($1,000)					459
COSTS/REVENUES PER TON ($/ton)					
System Cost					$ 17.65
System Revenue[5]					8.08
Net System					9.57
Landfill[6]					2.11
Total Net					$ 11.68

TABLE 12 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Includes 5 25-TPD units. Incinerators are designed to operate on a 24-hour basis. The extra unit provides reserve capacity for maintenance.

[3] Operators are on duty for 8-hour shifts. The shifts are split to allow for continuous operation. Wage rate is $5.80 per hour, which includes fringe benefits of 15 percent. The supervisor is on duty for one 8-hour shift at $7.80 per hour.

[4] Energy: Supplemental fuel is consumed at a rate of 5 percent of the BTU value of the input refuse. Operation conditions:

• Thermal value of refuse	5,000 BTU/pound
• Supplemental fuel	Natural Gas
• Cost of gas	$0.2776/therm
• Thermal value of therm	100,000 BTU

Mobile Equipment - operation conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[5] Revenue Factors:

• Percent combustibles in wastestream	80%
• Recovery rate	90%
• Market value: substitute value of coal	$1154/100 tons of combustible refuse @ 5000 BTU/pound

[6] Cost Factors:

• Weight Reduction	70%
• Cost to haul to landfill and disposal	$7/ton

TABLE 13. COST ANALYSIS FOR A REPRESENTATIVE MODULAR INCINERATOR WITH ENERGY AND FERROUS RECOVERY[1] (100 TPD)

			Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)						
Incinerator and boiler, complete in place[2]			$1800	15	0.117	$210
Magnetic Separator			30	5	0.250	8
Baler			30	5	0.250	8
Auxiliary Equipment			50	5	0.250	13
Small Front-End Loaders (3)		40				
Office Furniture, Refuse Bins		10				
Construction & land			410	20	0.101	41
Building: 10,000 ft^2 @ $\$30/\mathrm{ft}^2$		300				
Site Development: 20% of bldg		60				
Land: 5 acres @ \$10,000/acre		50				
TOTAL			$2320			$280
OPERATING COSTS ($1,000)						
Labor:[3]	6 operators @ \$72 1 supervisor @ \$16					$ 88
Supplies:	3% of labor & maint.					5
Energy:[4]	Supplemental fuel Stationary equipment Mobile loader Lighting Heat building		$ 36.0 3.6 3.2 0.7 1.3			45
Maint.	3% of total capital costs					70
Misc.:	(taxes, licenses, insurance, administrative and management costs) 1% of total initial capital costs					23
TOTAL						$231
TOTAL ANNUAL SYSTEM COSTS ($1,000)						$511
COSTS/REVENUES PER TON ($/ton)						
System Cost						$ 19.65
System Revenue[5]						9.16
Net System						10.49
Landfill[6]						1.46
Total Net						$ 11.95

TABLE 13 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] Includes 5 25-TPD units. Incinerators are desinged to operate on a 24-hour basis. The extra unit provides reserve capacity for maintenance.

[3] Operators are on duty for 8-hour shifts. The shifts are split to allow for continuous operation. Wage rate is $5.80 per hour, which includes fringe benefits of 15 percent. The supervisor is on duty for one 8-hour shift at $7.80 per hour.

[4] Energy: Supplemental fuel is consumed at a rate of 5 percent of the BTU value of the input refuse. Operation conditions are:

• Thermal value of refuse	5,000 BTU/pound
• Supplemental fuel	Natural gas
• Cost of gas	$0.2776/therm
• Thermal value of therm	100,000 BTU

Stationary Equipment - operation conditions are:

• Electric Power Consumption	5 kwh/ton
- Cost	$304/month

Mobile Equipment - operation conditions are:

• Gasoline Consumption	2.5 gallons/hour
- Cost	$0.60/gallon

[5] Revenue Factors:

• Steam ($8.08/input ton)	
- Percent combustibles in wastestream	80%
- Recovery rate	90%
- Market value: substitute value of coal	$1154/100 tons of combustible refuse @ 5000 BTU/pound
• Ferrous ($1.08/input ton)	
- Percent ferrous in wastestream	8%
- Recovery rate	90%
- Market value	15.00/ton FOB the recovery site

[6] Cost Factors:

• Steam: Weight Reduction	72%
• Ferrous: Weight Reduction	7.2%
• Cost to haul to landfill and disposal	$7/ton

- Newsprint
- Corrugated
- High-grade paper
- Mixed paper
- Glass (colors mixed or separated into clear, brown, and green glass)
- Aluminum
- Ferrous (bi-metal cans, tin-coated steel cans, or heavy ferrous such as white goods)

Potentially recoverable materials less likely to be source separated due to poor marketability, difficulty of identification, or low volume include:

- Kraft (brown) paper
- Non-ferrous metal, other than aluminum
- Plastics
- Organics
- Textiles
- Tires

The value of source-separated materials always is affected by their purity. Thus, most markets have specified maximum levels of contaminants that are acceptable. This leads to requirements for the preparation, and sometimes storage, of the materials, Table 14.

Considering the applicable situations and the types of materials that could be included, there are almost unlimited variations in source separation schemes. All depend on physically separating the desired material(s) from the wastestreams. From that point various combinations of accumulations, processing, and storage are possible before the material reaches the dealer, Figure 4. The potential variability of source separation systems led to a differentiation between those applicable to residential-type situations and those applicable to other wastestream generators included in the project.

Residential Systems--

Separation of materials in the home before mixing with other household wastes has been practiced in small cities. Materials commonly separated are newspapers, glass, and cans (aluminum

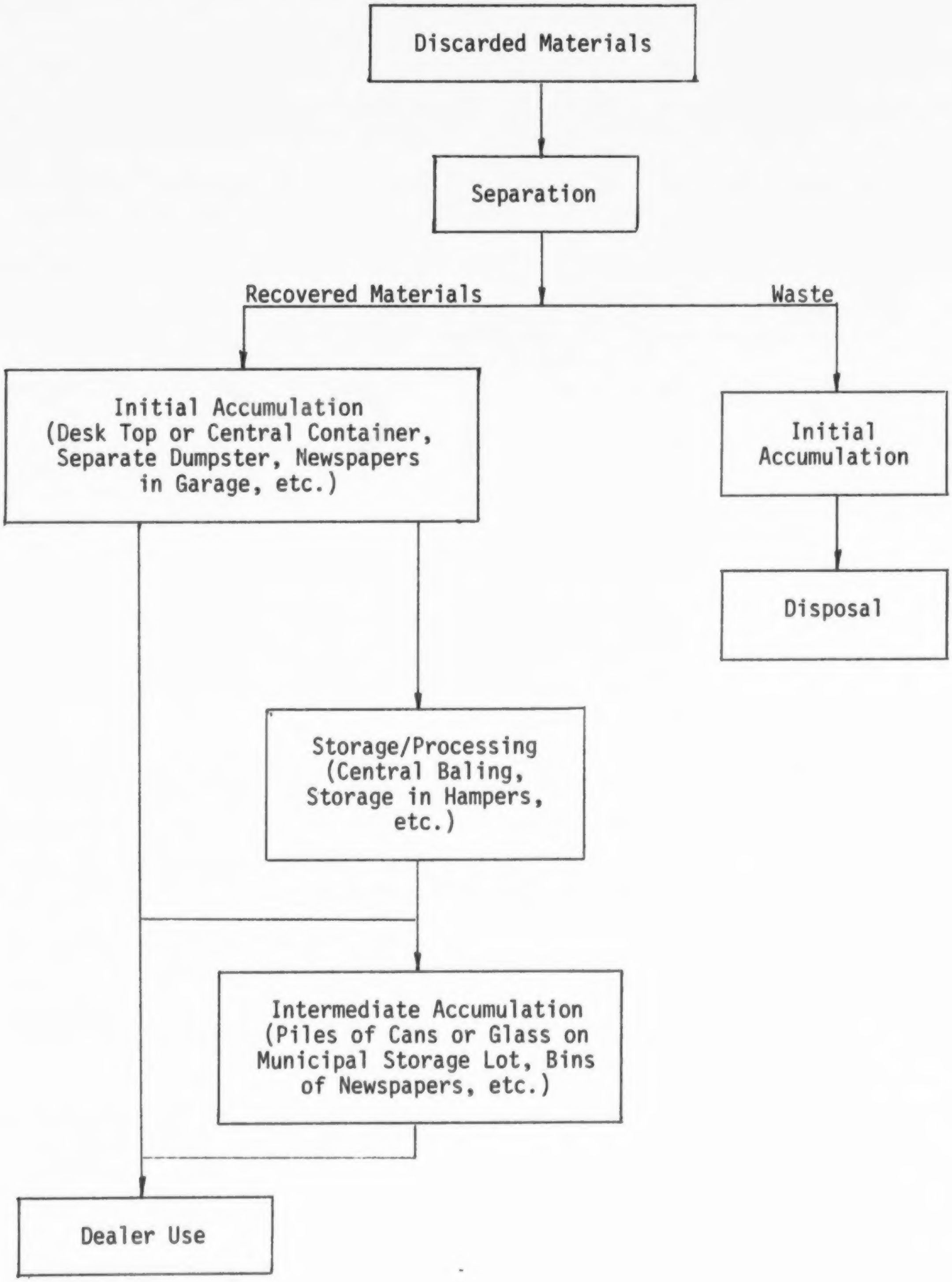

Discarded Materials
Separation
Recovered Materials
Waste
Initial Accumulation (Desk Top or Central Container, Separate Dumpster, Newspapers in Garage, etc.)
Initial Accumulation
Disposal
Storage/Processing (Central Baling, Storage in Hampers, etc.)
Intermediate Accumulation (Piles of Cans or Glass on Municipal Storage Lot, Bins of Newspapers, etc.)
Dealer Use

Figure 4. Process Flow Diagram-Source Separation

TABLE 14. TYPICAL PREPARATION REQUIREMENTS FOR RECYCLABLE MATERIALS*

• Newspapers:	Must be free of other kinds of paper and tied two ways with strong cord in stacks no more than 20 inches high.
• Corrugated Paper:	Must be clean and dry with no wax, plastic, or metal contaminants, and boxed, bundled, or baled securely.
• Mixed Paper:	Must be clean and dry with no wax or plastic contaminants.
• High-Grade (Office) Paper:	Contains only white ledger, computer tab cards, computer print-out, and other selected high-grade papers. No colored paper, carbon paper, plastic or non-paper contaminants.
• Glass:	Must be clean with all metal and plastic caps, lids, foil, rings, and coverings removed, and separated into clear, green and amber color categories. Glass should not be broken, nor do paper labels need to be removed. No pyrex, light bulbs, mirrors, flat glass, or ceramics should be included with container glass.
• Aluminum:	Cans must be clean and flattened; foil, trays, and twist-off bottle caps must be clean; "hard" aluminum (lawn furniture, siding, cookware, etc.) must be free of steel and plastic contaminants and separated from other grades.
• Tin/Ferrous:	Cans must be cleaned and flattened, with paper labels removed; other ferrous metal must be free of contaminating metals.
• Kraft (Brown) Paper:	Must be clean and dry and free of other kinds of paper (often included with corrugated).
• Non-Ferrous Metal:	Must be free of contaminanting metals and separated by metal type (copper, lead, zinc, brass, etc.)
• Plastic:	Must be clean and paper-free, thermoplastics only, and separated by type (polyethylene, polypropylene, polystyrene, etc.).
• Organics:	Food and yard wastes only; but may, for certain applications, contain paper; must be glass-, metal-, and plastic-free.
• Textiles:	Must be clean and free of synthetic fibers.

* SOURCE: Reference 5.

and/or other). The materials are prepared as required (as shown in Table 14 or otherwise) and temporarily stored.

Storage normally requires the use of cardboard boxes, separate trash cans, shopping bags, or no "container" at all, as in the case of newspapers stacked and tied in bundles. Common storage areas include garages, pantries, or closets, basements, carports, or storage sheds.

Periodically, the accumulated materials are removed from storage at the source and "collected". Collection may be by regular refuse collection crews using modified vehicles, special crews and vehicles, or the individual may take the materials to a collection point -- the recycling center approach. Collections from homes are usually, and optimally, made on a normal refuse collection day and on a regular schedule. This helps increase participation by minimizing inconvenience and by establishing a pattern for collection of the recyclables.

The materials are hauled directly to a dealer or accumulated until sufficient quantities are on hand to warrant transfer to the dealer. Newspapers are virtually the only material collected in large enough quantities such that a truck could economically haul its load directly from the collection route to the dealer. This would require the use of a separate vehicle for newspaper collection and a nearby dealer.

Other materials usually are hauled to an intermediate storage point. This point can serve simply as a transfer station where large quantities of recovered materials can be accumulated, and therefore, transported to market more economically, or where additional processing may take place. Different materials require various types of processing. Typical materials processing options are:

- Paper
  - shredded and baled
  - baled
  - compacted
- Glass
  - crushed by a hammermill
  - crushed in packer transport vehicle
- Cans
  - magnetic separation
  - baled

Additional equipment needs for such processing include storage bins, a building, front-end loader, baler, compactor, forklift, etc. This processing can increase the value of source-separated materials many times. A market survey conducted for recoverable materials in Lincoln County, Maine, for example, indicated that loose newspaper could be sold for $20 per ton, whereas baled newspaper would be purchased for $60 per ton. Likewise, loose corrugated had a value of $15 per ton, and baled corrugated $40 per ton (6).

Usually materials are stored in containers such as roll-off bins or in piles until sufficient quantities have been accumulated. At that point the materials are transferred to the dealer. Either the materials are delivered to the dealer or the dealer picks up the materials at the point(s) of accumulation.

The variations in approaches to residential source separation and the volatility of the secondary materials market make it difficult to analyze costs for this low-technology approach and generalize to other situations. One of the major problems with source separation systems is the unpredictable nature of market prices for the recovered materials. Therefore, it is desirable to secure long-term (1 to 5 years) contracts with a fixed price floor. Representative market prices for recoverable materials for both residential and other programs during 1978 are listed below (6), (7), (8):

Material	Price Range ($/ton)
High-grade paper	55-105
Newsprint	15-42
Corrugated	10-40
Mixed paper	7-25
Tin-coated steel cans	24-54
Glass	10-30
Aluminum	340-480

The wide range in prices results from:

- Geographic location of market
- Degree of prior processing of materials
- Quality/purity of materials
- Point of FOB
- Other economic factors

In order to present a typical residential source-seperation program, a scenario was developed for cost analysis purposes. A small city situation was assumed with 100 TPD of refuse generated. It is assumed that markets have been established for aluminum, tin-coated steel cans, mixed glass, and newspaper. Other assumptions concerning quantities recovered and prices are shown in Table 15.

All the separated materials, except for newsprint, are collected in a compartalized truck. The newsprint is hauled in a trailer which is attached to the truck. Householders are asked to place their separated materials at curbside on a regular collection day. A two-man crew collects the materials and hauls them to the city's processing center. At the center, the mixed glass is crushed and stored in barrels. The cans are passed through a magnetic separator. Steel and aluminum cans are separately baled and bales stored in the processing center. Newsprint also is stored in the processing center. Periodically, a heavy-duty truck is "rented" from another city agency and used to haul the glass, metal and newsprint to dealers.

Participation rates of 30 and 50 percent were assumed. Total net costs for the recovery system and landfilling the non-recovered waste were $8.16 and $7.78 per ton, respectively, Table 16.

Other Systems--

Source separation systems applicable to other wastestream generators are so widely varied that no situation could be considered typical. Likewise, no cost analysis was accomplished due to the extremely site-specific nature of the systems, costs, and revenues.

ANALYSIS

System Rating Criteria

In order to evaluate the alternative systems identified, rating were developed, Table 17. The criteria selected represent the characteristics of greatest concern (other than economic) in determining system applicability to small waste generators. Site specific factors, such as public acceptability, were not rated, although they are extremely important. These kinds of factors will be dealt with in detail in Section IV.

The concerns of small waste generators in selecting a resource recovery system are, in many ways, similar to the concerns of large municipalities. The following are important decision factors whether facility capacity is 100 TPD or 1000 TPD:

TABLE 15. ASSUMPTIONS FOR SOURCE SEPARATION COST ANALYSIS

Market	% of Waste Stream	Price FOB Dealer's Yard	Distance to Market (mi)	TPD Recovered	
				30% Participation	50% Participation
Newspaper	10	$20/ton loose	60	3	5
Mixed Glass	10	$15/ton crushed	25	3	5
Tin-coated steel cans	5	$40/ton baled	40	1.5	2.5
Aluminum cans	1	$340/ton baled	40	.3	.5

TABLE 16. COSTS ANALYSIS FOR A REPRESENTATIVE SMALL CITY SOURCE SEPARATION PROGRAM[1] (100 TPD)

		Initial Costs	Life (Years)	Amortization Factor (8%)	Annual Costs
CAPITAL COSTS ($1,000)					
Mobile Equipment		$ 24	5	0.250	$ 6
Compartmentalized truck	12				
Trailer and Forklift	12				
Stationary Equipment		32	5	0.250	8
Baler and Glass Crusher	20				
Magnetic Separator	10				
Newspaper Containers (4)	2				
Misc. Equipment and Office Furniture		5	5	0.250	1
Construction & land		136	20	0.101	14
Building: 3500 ft² @ $30/ft²	105				
Site Development: 20% of bldg	21				
Land: 1 acre @ $10,000/acre	10				
TOTAL		$197			$ 29
OPERATING COSTS ($1,000)					
Labor:[2] 2 operators					$ 24
Supplies: 3% of labor & maint.					1
Energy:[3]		$ 5.0			
Gasoline		3.1			
Heat building		0.7			
Electricity		1.2			
Maint.: 3% of total capital costs					6
Misc.: (administrative and management costs) 1% of total initial capital costs					2
TOTAL					$ 38
TOTAL ANNUAL SYSTEM COSTS($1,000)					$ 67
COSTS/REVENUE PER TON ($/ton)					
System Cost					$ 2.58
System Revenue @ 30% Participation[4]					0.42
System Revenue @ 50% Participation[5]					0.89
Net System Cost @ 30% Participation					2.16
Net System Cost @ 50% Participation					1.69
Landfill @ 30% Participation					6.45
Landfill @ 50% Participation					6.09
Total Net Cost for System and Landfill @ 30% Participation					$ 8.16
Total Net Cost for System and Landfill @ 50% Participation					$ 7.78

TABLE 16 - continued

Footnotes:

[1] Data calculated by SCS Engineers from literature and vendor sources.

[2] One crew member drives compartmentalized truck, while the other collects the materials. Both work in the processing center.

[3] Travel on route and to dealers average 500 miles per week @ 6 mpg and 60¢ per gallonn. Forklift uses equivalent of 3 gallons per day.

[4] Revenue as shown in Table 15 @ 30% participation, annual revenues = $10,884

[5] Revenue as shown in Table 15 @ 50% particpation, annual revenues = $23,140

[6] Cost Factors:

• Weight Reduction	7.8%
• Cost to haul to landfill and disposal	$7/ton

[7] Cost Factors:

• Weight Reduction	13%
• Cost to haul to landfill and disposal	$7/ton

TABLE 17. SYSTEM RATING CRITERIA

I. PERFORMANCE

A. Reliability: System and components proven to perform dependably and with minimum down-time.

Rating	Description
High	Proven performance with high reliability
Medium	Adequate performance with adequate reliability
Unacceptable	Inadequate performance with inconsistent reliability

B. Degree of Waste Volume Reduction

Rating	Description
High	>60%
Medium	30-59%
Low	0-29%

C Freedom from Maintenance/Simplicity

Rating	Description
High	Simple; minimal skills required for operation; few or no moving parts
Medium	Moderate; intermediate in mechanical complexity; operation requires some degree of skill and/or training
Low	Complex; involves sophisticated mechanical equipment; skilled and trained operators required

II. ENVIRONMENTAL ACCEPTABILITY

A. Meets all minimum standards for air, noise, water and land pollution

Rating	Description
Acceptable	Complies with minimum standards
Unacceptable	Does not meet standards

B. Maximizes resource recovery within technological limits

Rating	Description
High	Recovers maximum number of resources; > 60% of waste
Medium	Recovers moderate number of resources; 30-59% of waste
Low	Recovers few resources; <29% of waste stream

III. MARKETABILITY OF RECOVERED PRODUCT(S)

Rating	Description
High	Product(s) have ready markets
Medium	Product(s) are somewhat marketable, but prices subject to cyclical swings
Low	Product(s) difficult to market or have very low value

- System reliability
- Compliance with environmental standards
- Reduction in the amount of waste requiring final disposal
- Availability of markets for recovered products.

Certain other factors are of particular importance to small waste generators, especially since their primary activity or purpose is not solid waste management. These factors include infrequent maintenance and relatively simple technology which can be operated by persons with minimal skills or the ready availability of personnel with the necessary operation and maintenance abilities.

Ratings

Table 18 indicates how each of the seven systems discussed in this chapter were rated and summarizes the approximate cost data. The costs for the systems may appear to be high, but it should be kept in mind that they also include landfill costs for the unrecovered solid waste. In analyzing the rating, modular incineration and source separation clearly emerge as the highest rated systems. Additionally, these are the lowest cost systems.

Another important factor in assessing the feasibility of these systems is the degree of risk that must be assumed by the waste generator. Problems related to the comparative risks of each system are discussed below.

RDF--

RDF is a high-risk system for a number of reasons:

- Market uncertainty
- Economic risks due to larger investment
- Technological complexity

RDF production has been shown to be feasible on a large scale, but at 100 TPD the system is very expensive on a per ton basis. RDF would be economically viable on a small scale only if the price of RDF increased by about $4 per ton or if RDF could command an equivalent price on a BTU basis with coal (which is not likely in the near future). At the present time, RDF is not a desirable fuel due to the inconvenience and extra expense involved in its handling, storage and use. The high net cost and high degree of system complexity makes this system appear unattractive for a small waste generator.

TABLE 18. SYSTEM RATING

	System Rating Criteria (100 TPD System)						
	Reliability	Waste Volume Reduction	Freedom from Maintenance; i.e., Simplicity	Environmental Standards	Resource Recovery	Marketability of Product(s)	Net Cost/Ton*
Ferrous Recovery	Medium	Medium	Low	Acceptable	Low	Low	$15.38
Compost	Medium	Medium	Low	Acceptable	Medium	Low	26.70
Compost with Ferrous Recovery	Medium	High	Low	Acceptable	High	Low	26.05
RDF with Ferrous Recovery	Medium	High	Low	Acceptable	High	Medium	13.61
Incineration with Energy Recovery	High	High	Medium	Acceptable**	High	High	11.68
Incineration with Ferrous and Energy Recovery	Medium	High	Low	Acceptable**	High	Medium	11.95
Source Separation	Medium	Medium	High	Acceptable	Medium	Medium	8.16

* Cost of operating system minus revenues plus disposal of non-recovered material.

** May require external air pollution control equipment.

Ferrous Recovery--

The major risks involved with this system are economic. Because the price for ferrous fluctuates and a relatively large capital cost is necessary for this system, the potential return on investment is very low. Even at a market price of $40 per ton, the net cost of this system is $15.38 per ton. Since the majority of small waste generators produce far less than 100 TPD, the system also cannot be justified unless circumstances put a high value on volume reduction and subsequent landfill space savings.

Compost--

Compost systems combine the problems associated with RDF and ferrous recovery. The mechanical processing system requires a high capital investment, but the subsequent product has virtually no market. Many of the waste generators in this study, such as universities, garden apartments, and trailer parks, could potentially have use for compost. However, the high cost and high level of processing necessary for this system do not make mechanical composting appear worthwhile.

Modular Incineration--

Modular incineration has an environmental risk of potential production of air pollution. An ongoing EPA study is analyzing emissions from operation facilities. This study will determine the potential for air emissions from these incinerators.

Economic risk associated with modular units is not as great as that for RDF plants. Steam produced by modular incinerators is a marketable product and is in a form readily acceptable to industrial users. The market for the stream must be within a couple of miles from the generator, and the closer the user and generator are the higher the economic value of the steam.

Although it is a complex technology, it is easily operated by persons with moderate skills. Processing does not require multiple steps, and handling is minimal. Units are available in size from 3 TPD, thus making modular incinerators particularly applicable to small waste generators.

Source Separation--

Source separation also has the problem of variable demand for recovered materials. The major advantage of this system, however, is the relatively low capital investment required. It is also a highly flexible system as additional materials may be recovered as they become economically attractive. There is a moderate degree of inconvenience in handling, storage, and processing of the recovered materials.

Probably the major problems with this system is in establishing a high level of public participation and maintaining adequate purity of the recoverd materials. Despite these problems, the level of risk involved with this system is moderate. The degree of risk is sufficiently small enough for over 200 communities to have adopted source separation programs, (Personal communication. David Cohen, Environmental Protection Agency, Washington, D.C. August 17, 1978).

Conclusion

Modular incineration (recovering energy but not ferrous) and source separation have been identified as the two most feasible systems with the lowest relative costs and risks for small waste generators. The next section will assess the applicability of these systems to the specific waste generators identified in Section II.

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SECTION IV

APPLICABILITY OF SELECTED SYSTEMS TO WASTE GENERATORS

Modular incineration and source separation are the two systems that have been selected as being most applicable to small waste generators. In this chapter, the feasibility of implementing these systems for the specific waste generators described in Section II will be examined. The first part of this section describes the general and site-specific factors that decision-makers must consider before adoption of these systems. The second part presents recommendations for each waste generator, and the third discusses the impediments to implementation of these systems.

DECISION-MAKING CRITERIA

When selecting any solid waste management system, numerous decision-making criteria must be assessed, such as:

- Legal considerations
    - Can the waste generator negotiate contracts?
    - Can the waste generator enter into long-term contracts?
    - Who has control of the waste stream?
- Environmental constraints
    - Will the proposed system meet all applicable air, water and noise standards?
- Financial concerns
    - Does the waste generator have financing capabilities?
    - What type of financing method is most feasible?
- Institutional constraints
    - Can the waste generator own the solid waste management facility?
    - Does the generator have the expertise, capability, or desire to operate the facility?

  - Are substantial changes in present solid waste collection practices necessary?
  - Are building design and operations flexible enough to incorporate changes?
- Economic considerations
  - Is a market readily available for recovered products?
  - Will the proposed system cost more than the existing system?
  - What savings will result from the proposed system?
- Technical feasibility
  - Are waste stream characteristics and quantity compatible with the proposed system?
  - Is the system proven?
  - Is the system reliable?
  - Can the system be run by waste generator personnel?
- Community acceptance
  - Is public participation necessary?
  - Is the site or system controversial?

Although some of these considerations generally apply to broad resource recovery issues, and others are site specific characteristics, they must all be assessed for each individual situation. Generally, a system is designed for a particular site where all of these variables and questions can be readily identified.

EVALUATION

This analysis deals with "representative" waste generators; therefore, numerous assumptions concerning these variables have been made to facilitate the evaluation. These assumptions presuppose certain conditions under which the systems operate and make generalizations about the various waste generators.

General assumptions made which apply to both source separation and modular incinerator systems are:

- The waste generator has the legal authority to negotiate and enter into long-term contracts.

- An identifiable central authority has control over the waste stream.

- All applicable environmental standards will be met.

- The waste generator has financing capabilities.

- The generators are under no long-term solid waste management contracts.

- The generator will own and/or operate the proposed system.

- Markets are avaiable for recovered products at current average prices.

- Generators would be willing to change solid waste management systems if the proposed system is more economical.

- Existing system cost is the current combined collection and land disposal cost for all generators and is $28 per ton. Cost for disposal only is $7 per ton, (Personal communication. Sam Ziff, Browning Ferris Industries, Merrifield, Virginia. May 17, 1978).

- Per day costs are based on a 260 day per year operation

General assumptions made which apply to modular incineration are:

- Modular incinerators are assumed to be 50 percent efficient in converting potential energy to usable energy.

- Coal boilers are assumed to be 65 percent efficient.

- Natural gas boilers are assumed to be 70 percent efficient.

- Costs for energy from fossil fuels assumed as shown. Fuel costs are based on national averages, except for natural gas, which is the cost in Virginia, (Personal communication. M. Weiner, Washington Gas Light Company, Washington, D.C. July 27, 1978; S. Zvindarm, American Petroleum Institute, Washington, D.C. July 27, 1978; and Rosanne Schwaderer, Coal Week Magazine, Washington, D.C. July 24, 1978).

  Natural Gas = $2.50 per 10^6 BTU

  Oil = $1.67 per 10^6 BTU

  Coal = $1.00 per 10^6 BTU

- Natural gas was selected as auxiliary fuel for modular incinerators; however, oil could be used. The value of the output energy was calculated based on the equivalent BTU value for coal, making the cost/revenue estimates very conservative.

- No change in existing collection practices for any of the waste generators was necessary unless otherwise stated.

- Labor costs, including fringe benefits, are $6.50 per hour for laborers and loaders and $7.80 per hour for supervisors.

- Modular units less than 25 TPD require only building modifications for installation, whereas units larger than 25 TPD require their own buildings.

- Modular unit sizes for which costs were derived are listed below, (Personal communication. Lee Wiles, Air Pollution Control Products, Alexandria, Virginia. July 20, 1978):

24 Hr Per Day Operation	8 Hr Per Day Operation
3 - 4.3 TPD	3.3 - 4.4 TPD
5.2 - 6.7 TPD	4.4 - 6.4 TPD
5.6 - 8.2 TPD	6 - 8.4 TPD
9.7 - 13.2 TPD	8.4 - 11.2 TPD
25 TPD	
25 TPD	

General assumptions made which apply to source separation are:

- Participation rates of 30 percent and 50 percent for newspaper, glass, ferrous and aluminum.

- Total net cost for recovery are $8.16 per input ton - 30 percent participation and $7.78 per input ton - 50 percent participation, Section III-Table 9.

- A participation rate of 70 percent for high-grade paper recovery.

- A participation rate of 70 percent for corrugated recovery, unless otherwise stated.

- The following prices for various materials:

- Newspaper (1):	$ 34 per ton, baled, delivered
	$ 15 per ton, loose, delivered
- Corrugated (1):	$ 10 per ton, compacted, picked-up
	$ 30 per ton, baled, picked-up
- Glass (5):	$ 30 per ton, delivered (Personal communication. Murray Fox, Recycling Enterprises, Inc., Oxford, Massachusetts. July 7, 1978; and Peter Karter, Resource Recovery Systems, Inc., Branford, Connecticut. July 7, 1978).
- Ferrous (2):	$ 40 per ton, flattened, delivered
- Aluminum:	$340 per ton, flattened, delivered (Personal communication. Robert Testin, Reynolds Aluminum, Richmond, Virginia. July 11, 1978).
- High-Grade Paper (1):	$ 55 per ton, loose, picked-up

- A maximum of 100 miles distance to market for delivered materials.

SYSTEM RECOMMENDATIONS

Matrices were developed for each waste generator which show the applicability of modular incineration, source separation, and/or a combination of the two systems. These matrices define the minimum conditions under which each of these systems are economically feasible. A detailed discussion of how these matrices were developed for each system is given below.

Modular Incineration

The procedure used to evaluate the applicability of modular incineration is indicated as follows:

Step 1: Determine whether a market exists for the energy.

Step 2: Determine costs of incineration.

a. Manufacturers information was obtained on incinerator sizes available and their costs.

b. Total annual costs, including capital, operating, and ash collection and landfill disposal (at $28 per ton) were determined for each unit size available.

c. The smallest energy recovery unit currently available which operates on a 24 hour per day basis processes 3 to 4.3 tons per day. The smallest 8 hour per day unit processes 3.3 to 4.4 tons per day. The 24 hour per day units are more expensive due to additional equipment (e.g., automatic ash handling) and operating costs necessary. However, many users may require 24 hour per day steam production rather than an interrupted steam supply.

d. The BTU value of the waste stream is established for each waste generator and is dependent on waste stream composition. Based on information developed in Section II, a typical waste stream composition for each generator was defined. Various waste stream components have the following BTU values (3):

Paper	15.5 x 10^6 BTU per ton
Plastic	36 x 10^6 BTU per ton
Organics	4 x 10^6 BTU per ton
Wood	16 x 10^6 BTU per ton

Therefore, an example of how the BTU value of a waste stream is derived is indicated below:

Typical Waste Stream	BTU Value
Paper - 35%:	(15.5 x 10^6BTU/ton) x 0.35 = 5.4 x 10^6 BTU/ton
Plastic - 10%:	(36 x 10^6BTU/ton) x 0.10 = 3.6 x 10^6 BTU/ton
Organics- 10%:	(4 x 10^6BTU/ton) x 0.10 = 0.4 x 10^6 BTU/ton
	Total=9.4 x 10^6BTU/ton=4700 BTU/lb

Revenues for steam vary depending on the BTU value of the waste. For example, a ton of solid waste with a BTU value of 5,000 BTU per pound has a heating value of 10 x 10^6 BTU, which at \$1.00 per 10^6 BTU equals \$10.00. A ton of solid waste with a BTU value of 7,000 BTU per pound has a heating value of 14 x 10^6 BTU, and is worth \$14.00. The BTU values for the waste generators ranges from 5,000 to 7,500 BTU per pound. Therefore, revenues for steam were determined for each BTU value represented.

e. Net costs for each unit equalled the total annual costs minus the steam revenues at various BTU values. These net costs were compared with the cost of existing collection and landfill disposal systems handling an equivalent amount of waste. Breakeven points were established whereby the cost of incinerator units processing a minimum TPD was equal to or less than the existing system.

Step 3: Determine solid waste generation rates for each generator. An average range of rates was established for each generator as discussed in Section II.

Step 4: Establish minimum size generators based on different generation rates for which modular incineration is feasible. For example, typical hospital waste generation rates range between 10 and 25 pounds per bed per day. If the smallest economically feasible modular incinerator processes 4 TPD, then two minimum conditions exist:

- Condition 1: At 10 pounds per bed per day, an 800 bed hospital will generate the required four tons per day.
- Condition 2: At 25 pounds per bed per day, a 320 bed hospital is the minimum size necessary.

In order to aid in evaluating the applicability of modular incineration to a broader range of criteria than listed above, a series of graphs were prepared for each waste stream generator considered as a possible user of this system. The graphs allow for economic evaluation of this approach when certain site specific data are known. The graphs and instructions are included in Appendix G.

Source Separation

Step 1: Materials to be recycled were selected based on percent present in waste stream and amount generated per day. Markets for materials determined to be economically recoverable were assumed to exist.

Step 2: Determine costs of source separation.

a. Determine incremental costs of source separation compared to existing system.

b. Estimate new capital costs plus incremental operating costs plus collection and disposal cost for non-source separated materials to determine total annual costs. These vary depending on the type of materials recovered, the type of waste generator, and the amount of materials recovered.

c. Estimate revenues from source separation. These are equal to the revenue from the sale of materials.

d. Net cost of a source separation system equals total annual cost minus revenue. This net cost is compared with the cost of the existing collection and disposal system handling an equivalent amount of waste. Breakeven points were established whereby the cost of the source separation system together with the modified existing system is equal to or less than the cost of the existing system.

Step 3: Generation rates and waste stream composition are established, again based on Section II information.

Step 4: Minimum size generators are established based on different generation rates. For example, it was determined that high-grade paper represents 43 percent of the waste stream in office buildings. At a recovery rate of 70 percent, 0.075 TPD is the breakeven point.

- Condition 1: At a generation rate of 1 pound per office employee per day, a minimum size office of 150 employees are required to generate 0.075 TPD.

- Condition 2: At a generation rate of 1.5 pounds per office employee per day, a minimum size of 100 employees is necessary.

Modular Incineration and Source Separation

Step 1: Recalculate BTU value of waste stream due to removal of combustible materials through source separation. Using Table 19, locate the sub-table for appropriate BTU value of waste stream.

TABLE 19. BTU AND FUEL SAVINGS ADJUSTMENT FACTORS

5000 BTU/lb

	% Reduction in Waste Stream									
MATERIAL	10	20	30	40	50	60	70	80	90	100
Newspaper	.83	.66	.49	.32	.15					
Corrugated	.84	.68	.52	.36	.20					
High-Grade Paper	.83	.66	.49	.32	.15					
Mixed Paper	.85	.70	.55	.40	.25					
Aluminum Cans										
Ferrous Cans				NO BTU VALUE						
Glass										

5500 BTU/lb

	% Reduction in Waste Stream									
MATERIAL	10	20	30	40	50	60	70	80	90	100
Newspaper	.85	.69	.54	.38						
Corrugated	.85	.71	.56	.42	.27	.13				
High-Grade Paper	.85	.69	.54	.38	.23					
Mixed Paper	.86	.73	.59	.45	.32	.18				

6000 BTU/lb

	% Reduction in Waste Stream									
MATERIAL	10	20	30	40	50	60	70	80	90	100
Newspaper	.86	.72	.58	.43	.29					
Corrugated	.87	.73	.60	.47	.33	.20				
High-Grade Paper	.86	.72	.58	.43	.29	.15				
Mixed Paper	.88	.75	.63	.50	.38	.25	.13			

7000 BTU/lb

	% Reduction in Waste Stream									
MATERIAL	10	20	30	40	50	60	70	80	90	100
Newspaper	.88	.76	.64	.51	.39					
Corrugated	.89	.77	.66	.54	.43	.31				
High-Grade Paper	.88	.76	.64	.51	.39	.27	.15			
Mixed Paper	.89	.79	.68	.57	.46	.36	.25	.14		

7500 BTU/lb

	% Reduction in Waste Stream									
MATERIAL	10	20	30	40	50	60	70	80	90	100
Newspaper	.89	.77	.66	.55	.46					
Corrugated	.89	.79	.68	.57	.47	.39	.25			
High-Grade Paper	.89	.77	.66	.55	.46	.32	.22			
Mixed Paper	.90	.80	.70	.60	.50	.40	.30	.20	.10	

Source: SCS Engineers based on energy content of removed material as referred in the text.

Find material(s) being separated in the vertical column. Move across the table to percent value equal to the percent of material being recovered. Read adjustment factor and multiply BTU value of waste stream by this factor to determine the new BTU value of the waste stream. For example, in a waste stream with 7,000 BTU per pound, where corrugated is 20 percent of the waste stream and 70 percent of that is recovered, what is the energy content of the remaining waste? The recovered paper represents 14 percent of the waste stream. The adjustment factor for corrugated from the 7,000 BTU per pound table is between 0.89 and 0.77. Interpolation yields a factor of 0.84. Thus, the remaining waste contains 0.84 x 7,000 BTU per pound or 5,880 BTU per pound.

Step 2: Recalculate energy revenues based on adjusted BTU value for waste stream.

Step 3: Determine new modular incineration net costs based on adjusted revenues and adjusted TPD capacity.

Step 4: Establish new breakeven point for each waste generator where modular incineration is feasible. These new breakeven points will generally be at higher TPD capacity due to the reduction in BTU value of the waste.

Step 5: Determine the net costs for source separation system and modular incineration together using the new incineration breakeven points. This is determined by computing the total capital and operating costs for both systems, plus the cost of collection and disposal of residue, minus the revenue from recovered energy and materials.

Step 6: Compare the net cost of the combined systems with the cost for the existing collection and disposal system. A new breakeven point is established for the new combined system if the net costs are less than or equal to the existing system.

For example, if university waste has 6,000 BTU per pound and high-grade paper is source-separated at 50 percent participation, 7.5 percent of the waste stream is removed. The new BTU value of the waste is (.895)(6,000) = 5,370 BTU per pound. At this reduced rate, the breakeven point for modular incineration is a 4.4 TPD unit. Due to the 7.5 percent reduction in the waste stream, 4.8 TPD is the minimum amount of waste required to yield 4.4 TPD to the incinerator. Costs for this example were calculated using the approaches for source separation and modular incineration shown in Section III with costs converted to a daily basis. These costs are summarized below:

- Total cost = $292 per day
  - Modular incineration capital and operating costs = $226 per day
  - -- Collection and disposal of 30 percent residue = $36 per day
  - -- Capital and operating cost of source separation system = $30 per day
- Total Revenue = $165 per day
  - -- Energy revenue = $143 per day
  - -- Material revenue = $22 per day
- Net cost = $127 per day
- Cost of existing system = ($28 per ton) x (4.8 TPD) = $134 per day.

Therefore, the combined system of modular incineration and source separation of high-grade is economical at greater than 4.8 TPD.

Step 7: Generation rates based on Section II information are determined.

Step 8: Determine minimum size generator. At a generation rate of 1 pound per student per day, a university with at least 9,600 students is necessary to generate 4.8 TPD. If the rate is 1.5 pounds per student per day, a student body size of 6,400 is the minimum.

Following is a detailed discussion of each waste generator and its applicability matrix.

Airports

Airport solid waste is assumed to have the following characteristics:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	50	7.8
Plastic	10	3.6
Wood	6	1.0
Organics	15	0.6
Other (e.g.,glass,metals)	19	---
Total	100	13.0

= 6,500 BTU per pound

These characteristics are a composite of an airport that has a passenger terminal, an air freight area, an aircraft service area, and an aircraft maintenance base. Larger airports usually have all four of these activities, whereas smaller ones may not. However, the BTU value of the waste will probably not vary significantly. Generation rates; however, could be quite different depending on whether all four of these airport activities are present or not. Typical generation rates for each area are listed below:

Terminal - 0.5 pounds per passenger per day

Air Freight - 7 pounds per ton cargo per day

Aircraft Service Center - 1 pound per passenger per day

Aircraft Maintentance Base - 2.2 pounds per passenger per day

As can be seen, depending on the combination of airport activities, various rates may apply, but rates of 0.25, 0.5, and 1.5 pounds per passenger per day were selected as representative.

It was determined that modular incineration was feasible for wastes from the entire airport, as shown in Table 20. (New system cost per day is less than existing system cost per day.) Corrugated recovery and baling was deemed viable from the air freight area and the aircraft maintenance area as it is concentrated in these areas. Metal recovery is currently practiced by many airports with maintenance areas and therefore this alternative was not investigated.

TABLE 20. RESOURCE RECOVERY APPLICABLE TO AIRPORTS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 80,000 passengers/day	Yes- $\$1/10^6$ BTU		6500	10	.25 lb/ passenger/ day	Paper 50% Plastic 10% Wood 8% Organics 15% Other 16%	24 hr/ day	$280	$269
Condition 2 40,000 passengers/day	"		"	"	.5 lb/ passenger/ day	" "	"	"	"
Condition 3 13,350 passengers/day	"		"	"	1.5 lb/ passenger/ day	" "	"	"	"
Condition 4 32,000 passengers/day	"		"	4	.25 lb/ passenger/ day	" "	8 hr/ day	$112	$107
Condition 5 10,000 passengers/day	"		"	"	.5 lb/ passenger/ day	" "	"	"	"
Condition 6 5,350 passenger/day	"		"	"	1.5 lb/ passenger/ day	" "	"	"	"
SOURCE SEPARATION									
Condition 1 Airfreight area, 200 TPD Cargo		Corrugated $30/ton		.7	7 lbs/ton cargo/ day	Corrugated 32%	70%	$ 9	$ 9
Condition 2 Aircraft Maintenance Base-1,150 employees		"		1.3	2.2 lbs/ employee/ day	Corrugated 36%	70%	$ 18	$ 18

An analysis of source separation with modular incineration was not done because not all airports have freight and maintenance areas. Site specific evaluations would be required to determine the applicability of this system. However, it is possible that such a system will work for the large airports. Figures 5 and 6 show the breakeven points for corrugated recovery.

Shopping Centers

Waste composition for this generator is assumed to be:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/ton
Paper	80	11.3
(Corrugated-52)		
Plastics	7.5	2.7
Other (e.g., glass)	12.5	---
Total	100	14
		= 7,000 BTU per pound

Waste generation from regional shopping centers were determined to typically be 20, 25, and 30 pounds per 1,000 square feet gross leasable area (SFGLA) per day. Most shopping malls are not presently designed to easily allow changes in solid waste handling practices. However, it was assumed for this analysis that existing practices would be modified somewhat.

Modular incineration is feasible over the whole range of regional shopping mall sites. As seen in Table 21, source separation of corrugated was analyzed and it was determined to be feasible under certain conditions. It was assumed that separate compactors would be installed by the paper stock dealers for a small rental fee in the shopping mall at various locations exclusively for corrugated disposal. It is assumed that the paper stock dealer will pick-up the compacted corrugated and the shopping center would receive $10 per ton. Waste management is not handled by each individual store, but by a central mall management. Figure 7 shows the breakeven point for corrugated recovery; i.e., in all shopping center with more than 200,000 SFGLA. It was also determined that source separation of corrugated and modular incineration combined are also feasible.

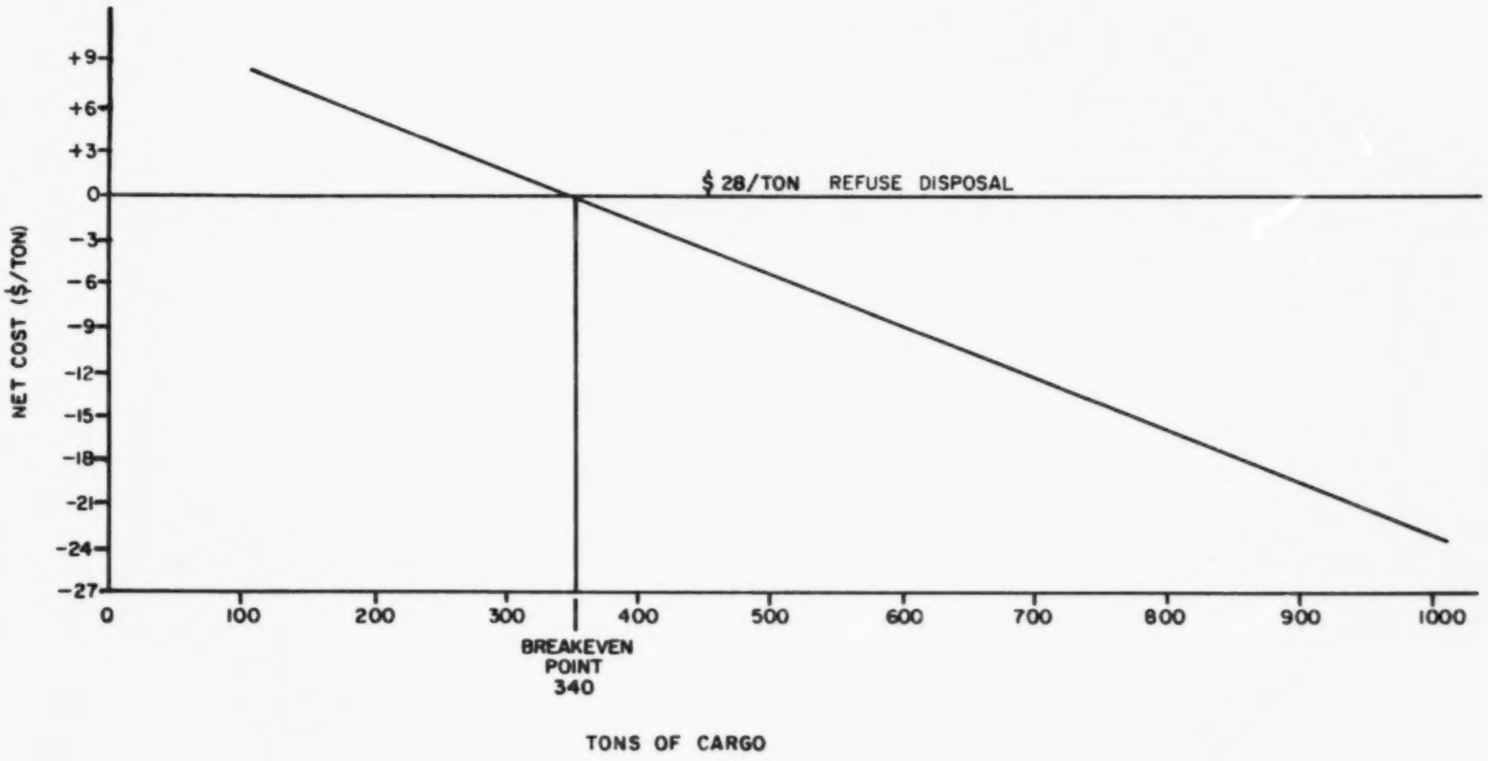

Figure 5. Air freight area - corrugated recovery.

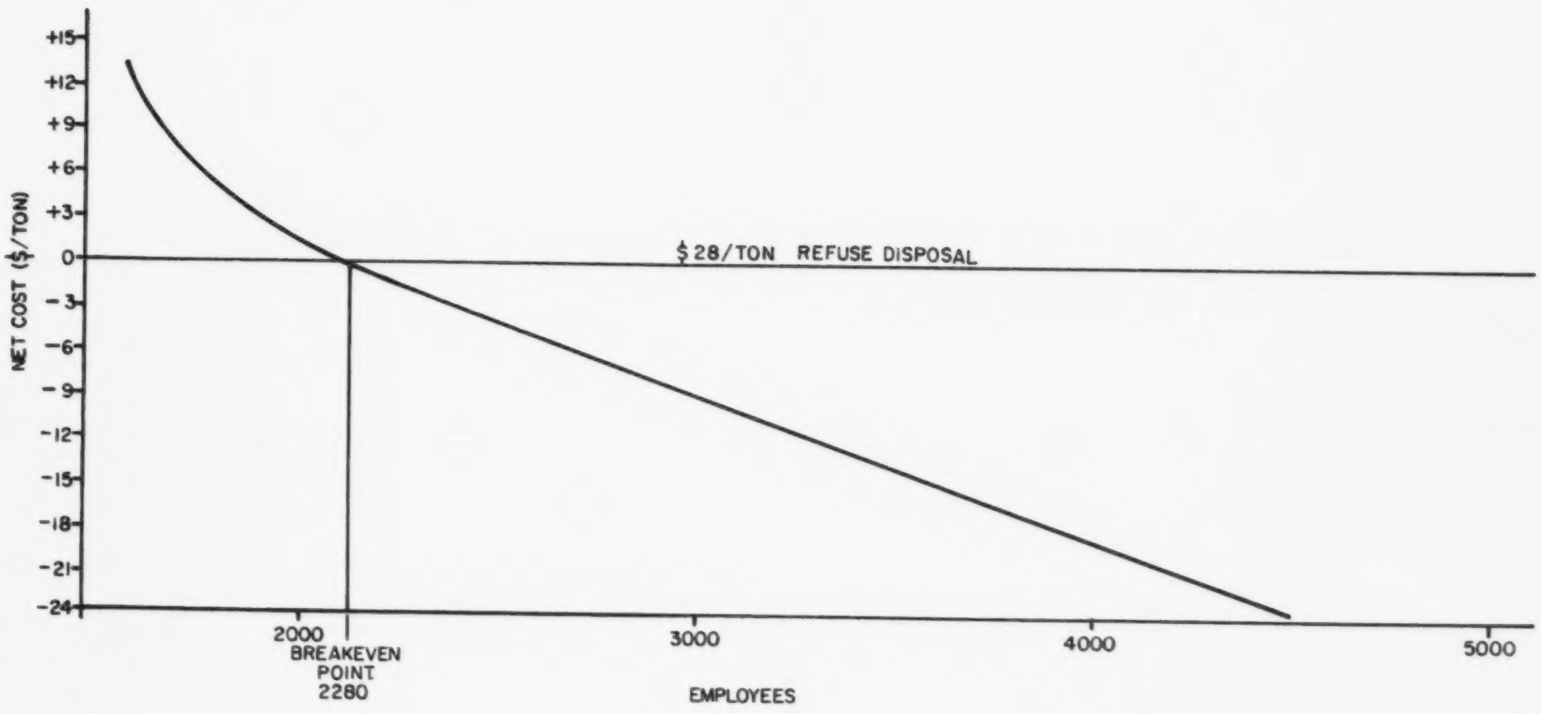

Figure 6. Airport maintenance base - corrugated recovery.

TABLE 21 RESOURCE RECOVERY APPLICABLE TO SHOPPING CENTERS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 800,000 SFGLA*	Yes- $1/10^6 BTU	N/A	7000	8	20 lbs/1000 SFGLA/day	Paper 80% Plastic 7.5% Other 12.5%	24 hr/ day	$224	$220
Condition 2 640,000 SFGLA	"	"	"	"	25 lbs/1000 SFGLA/day	"	"	"	"
Condition 3 535,000 SFGLA	"	"	"	"	30 lbs/1000 SFGLA/day	"	"	"	"
Condition 4 400,000 SFGLA	"	"	"	4	20 lbs/1000 SFGLA/day	"	8 hr/ day	$112	$104
Condition 5 320,000 SFGLA	"	"	"	"	25 lbs/1000 SFGLA/day	"	"	"	"
Condition 6 265,000 SFGLA	"	"	"	"	30 lbs/1000 SFGLA/day	"	"	"	"
SOURCE SEPARATION									
Condition 1 280,000 SFGLA	N/A	Corrugated $10/ton		2.8	20 lbs/1000 SFGLA/day	Corrugated 52%	70%	$ 78	$ 78
Condition 2 224,000 SFGLA		"		"	25 lbs/1000 SFGLA/day		"	"	"
Condition 3 1[illegible],000 SFGLA		"		"	30 lbs/1000 SFGLA/day	"	"	"	"
MODULAR INCINERATION and SOURCE SEPARATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 1,560,000 SFGLA	$1/10^6 BTU	Corrugated $10/ton	4116	15.6 (10 TPD MOD INC)	20 lbs/1000 SFGLA/day	Corrugated 52%	24 hr/ day 70%	$437	$404
Condition 2 1,250,000 SFGLA	"	"	"	"	25 lbs/1000 SFGLA/day	"	"	"	"
Condition 3 1,040,000 SFGLA	"	"	"	"	30 lbs/1000 SFGLA/day	"	"	"	"
Condition 4 630,000 SFGLA	"	"	"	6.3 (4 TPD MOD INC)	20 lbs/1000 SFGLA/day	"	8 hr/ day 70%	$176	$163
Condition 5 504,000 SFGLA	"	"	"	"	25 lbs/1000 SFGLA/day	"	"	"	"
Condition 6 420,000 SFGLA	"	"	"	"	30 lbs/1000 SFGLA/day	"	"	"	"

* SFGLA: Square Feet Gross Leasable Area.

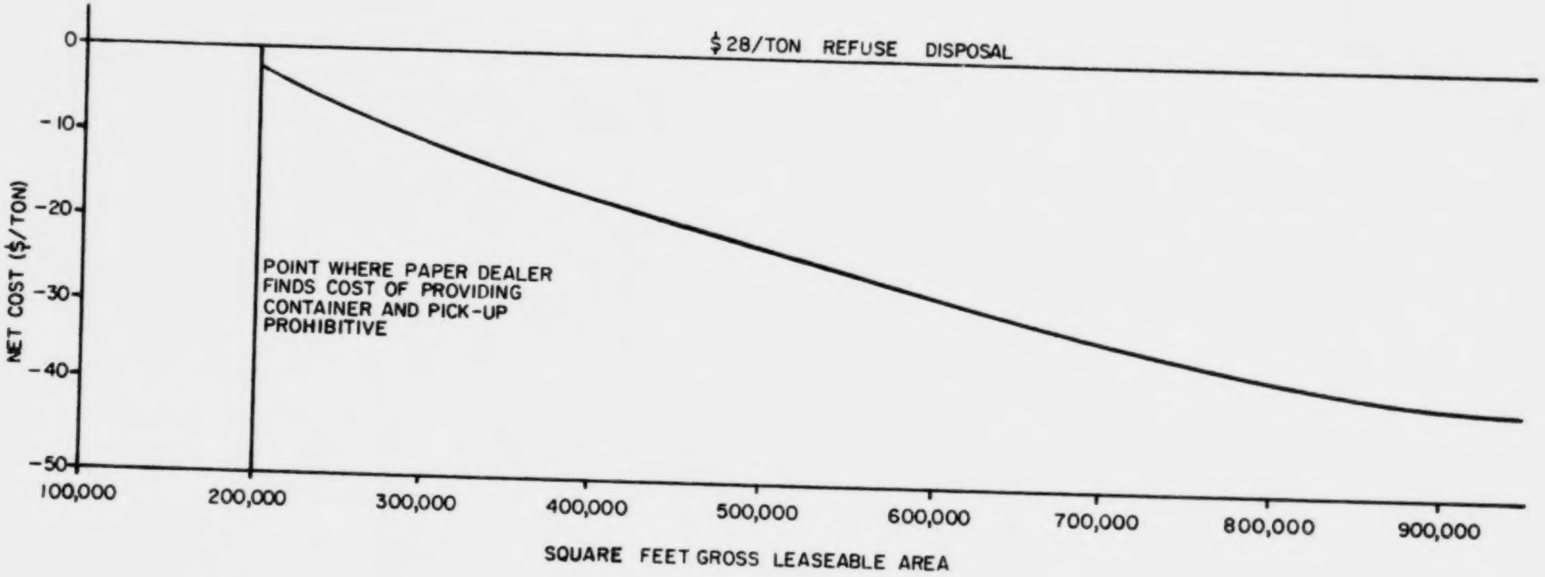

Figure 7. Shopping centers-corrugated recovery.

Hospitals

The composition of typical hospital waste is described below:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	40	6.2
Plastics	15	5.4
Organics	25	1.0
Misc.	10	1.4
Other(e.g.,glass)	10	---
Total	100	14
		= 7,000 BTU per pound

Generation rates vary widely between hospitals dependent upon the quantity of disposable items in use. The trend is toward increased use of these items due to their convenience, despite increased solid waste management costs that result. Therefore, generation rates of 10, 15, 20 and 25 pounds per bed per day were used. Bed capacity of 7,200 hospitals in the United States was surveyed and the results showed the following distribution (4):

Bed Capacity	Percent of Hospitals
0 - 50	26
51 - 100	24
101 - 250	25
251 - 500	15
Over 500	10

Table 22 indicates that modular incineration is feasible in hospitals with greater than 300 beds and high generation rates. Thus, this system may be applicable to over 20 percent of the hospitals.

Due to the problems of contamination from infectious and other hazardous wastes, source separation was not investigated for hospitals.

TABLE 22 RESOURCE RECOVERY APPLICABLE TO HOSPITALS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition		Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 1,600 beds	Yes- $1/10^6$ BTU	N/A	7000	8	10 lbs/ bed/day	Paper 40% Plastic 15% Organics 25%	Misc 10% Other 10%	24 hr/ day	$224	$220
Condition 2 1,067 beds	"	"	"	"	15 lbs/ bed/day	"	"	"	"	"
Condition 3 800 beds	"	"	"	"	20 lbs/ bed/day	"	"	"	"	"
Condition 4 640 beds	"	"	"	"	25 lbs/ bed/day	"	"	"	"	"
Condition 5 800 beds	"	"	"	4	10 lbs/ bed/day	"	"	8 hr/ day	$112	$104
Condition 6 533 beds	"	"	"	"	15 lbs/ bed/day	"	"	"	"	"
Condition 7 400 beds	"	"	"	"	20 lbs/ bed/day	"	"	"	"	"
Condition 8 320 beds	"	"	"	"	25 lbs/ bed/day	"	"	"	"	"

Prisons

A typical prison waste stream has the following BTU value and composition:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	59	7.7
(Corrugated-23)		
Plastics	8	2.9
Organics	10	0.4
Other(e.g.,glass,metals)	23	---
Total	100	11.0
		= 5,500 BTU per pound

Waste generation rates for prisons do not include prison industrial areas as this type of activity is site-specific. Therefore, generation rates of 4, 5, and 6 pounds per inmate per day were used. It was determined that corrugated was the most feasible material for recovery. Ferrous is currently recovered at many prisons in conjunction with industrial activities, and recovery potential of this material should be determined on an individual basis.

Since corrugated is generally concentrated in the prison supply area, a fairly high recovery rate of 80 percent was used. It was assumed that prisoners would be used to collect and bale the corrugated at a wage rate of $0.35 per hour, (Personal communication. Glenn Carpenter, Department of Justice, Washington, D.C. June 9, 1978). The additional time needed to perform these tasks was estimated at 10 hours per 100 inmates per week. For modular incineration, it is assumed that outside labor would be hired to operate the energy recovery facility. The two largest Federal prisons have about 2,000 inmates. The other 42 institutions have prison populations of about a thousand or less (5). The current trend in prison construction is toward smaller facilities with maximum inmate populations of 500, (Personal communication. Glenn Carpenter, Department of Justice, Washington, D.C. June 9, 1978). Therefore, modular incineration is shown in Table 23 to be feasible in only the largest existing prisons and only on an 8 hour per day basis with waste generation rates greater than 5 pounds per inmate per day. Corrugated recovery appears to be feasible for most prisons, while a combined modular incineration and corrugated recovery system is feasible only in the very largest prisons at high generation

TABLE 23 RESOURCE RECOVERY APPLICABLE TO PRISIONS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 5,500 inmates	Yes- $1/10^6 BTU	N/A	5500	11	4 lbs/ inmate/ day	Paper 59% Other 23% Plastic 8% Organics 10%	24 hr/ day	$308	$284
Condition 2 4,400 inmates	"	"	"	"	5 lbs/ inmate/ day	" "	"	"	"
Condition 3 3,670 inmates	"	"	"	"	6 lbs/ inmate/ day	" "	"	"	"
Condition 4 4,400 inmates	"	"	"	4.4	4 lbs/ inmate/ day	" "	8 hr/ day	$123	$112
Condition 5 1,760 inmates	"	"	"	"	5 lbs/ inmate/ day	" "	"	"	"
Condition 6 1,470 inmates	"	"	"	"	6 lbs/ inmate/ day	" "	"	"	"
SOURCE SEPARATION									
Condition 1 750 inmates	N/A	Corrugated $30/ton	"	1.5	4 lbs/ inmate/ day	Corrugated 23%	80%	$ 42	$ 42
Condition 2 600 inmates	"	"	"	"	5 lbs/ inmate/ day	"	"	"	"
Condition 3 500 inmates	"	"	"	"	6 lbs/ inmate/ day	"	"	"	"

MODULAR INCINERATION and SOURCE SEPARATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 2,700 inmates	Yes- $1/10^6 BTU	Corrugated $30/ton	3,960	5.4	4 lbs/ inmate/ day	Corrugated 23%	8 hr/ day 80%	$151	$120
Condition 2 2,160 inmates	"	"	"	"	5 lbs inmate/ day	"	"	"	"
Condition 3 1,800 inmates	"	"	"	"	6 lbs/ inmate/ day	"	"	"	"

rates. Figure 8 shows the breakeven point for corrugated recovery.

Universities

Waste from a typical university was assumed to have the following characteristics:

Component	Percent in Waste Stream	10^6 BTU/Ton
Paper	65	10.1
(High Grade-15)		
Plastics	3	0.1
Organics	10	0.4
Misc.	4	0.4
Other(e.g.,glass)	18	---
Total	100	12.0

= 6,000 BTU per pound

Generation rates of 1, 1.5, and 2 pounds per student per day were used. It is assumed that currently university crews collect and transport solid waste to a landfill for disposal. In the case of modular incineration, the waste is transported to the unit instead. With source separation, separated materials are collected by maintenance employees and transported by the university crews to a central processing point on campus. It was determined that high-grade paper had the greatest recycling potential. Additional collection time for high-grade was estimated at 1 hour per 100 students per month. The high-grade paper is baled prior to pick-up by the dealer. Table 24 indicates that all three systems are feasible for university situations. Figure 9 shows the breakeven point for high-grade paper recovery.

Office Buildings

The composition and BTU value of the waste stream for a typical office building is assumed as follows:

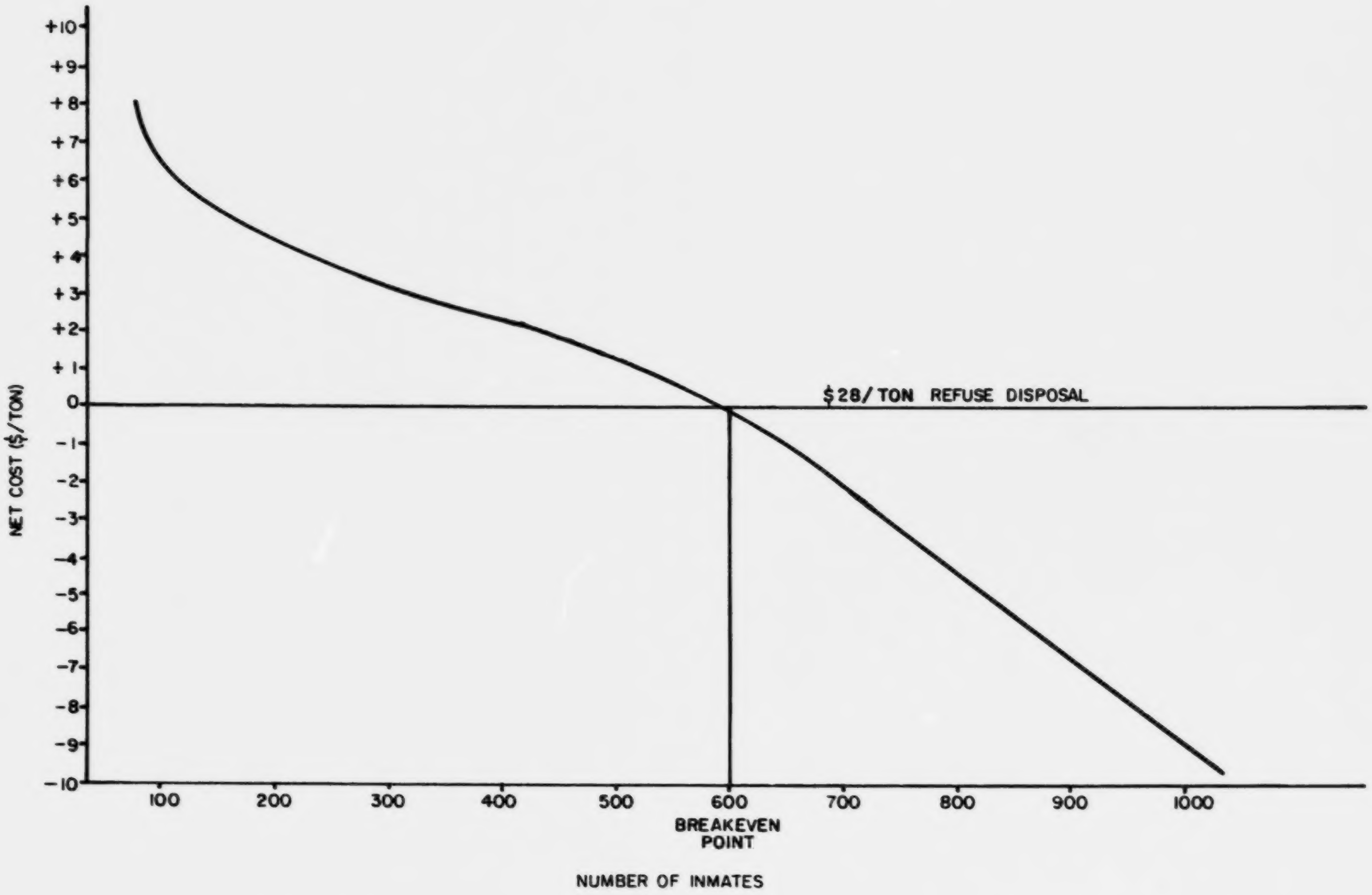

Figure 8. Prisons - corrugated recovery.

TABLE 24 RESOURCE RECOVERY APPLICABLE TO UNIVERSITIES

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 22,000 students	Yes- $\$1/10^6$ BTU	N/A	6,000	10	1 lb/ student/ day	Paper 65% Misc 4% Plastic 3% Other 18% Organics 10%	24 hr/ day	$308	$275
Condition 2 14,670 students	"	"	"	"	1.5 lb/ student/ day	" "	"	"	"
Condition 3 11,000 students	"	"	"	"	2 lb/ student/ day	" "	"	"	"
Condition 4 8,800 students	"	"	"	4.4	1 lb/ student/ day	" "	8 hr/ day	$123	$108
Condition 5 5,870 students	"	"	"	"	1.5 lb/ student/ day	" "	"	"	"
Condition 6 4,400 students	"	"	"	"	2 lb/ student/ day	" "	"	"	"
SOURCE SEPARATION									
Condition 1 9,750 students	N/A	High-grade paper- $55/ton		4.9	1 lb/ student/ day	High-grade paper 15%	50%	$137	$137
Condition 2 6,500 students	"	"		"	1.5 lbs/ student/ day				
Condition 3 4,875 students	"	"		"	2 lb/ student/ day				

MODULAR INCINERATION and SOURCE SEPARATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 23,800 students	$\$1/10^6$ BTU	High-grade paper- $55/ton	5,370	11.9 (11 TPD MOD INC)	1 lb/ student/ day	High-grade paper 15%	24 hr/ day 50%	$333	$300
Condition 2 15,870 students	"	"	"	"	1.5 lb/ student/ day	"	"	"	"
Condition 3 11,900 students	"	"	"	"	2 lb/ student/ day	"	"	"	"
Condition 4 9,600 students	"	"	"	4.8 (4.4 TPD MOD INC)		"	8 hr/ day 50%	$134	$127
Condition 5 6,400 students	"	"	"	"		"	"	"	"
Condition 6 4,800 students	"	"	"	"		"	"	"	"

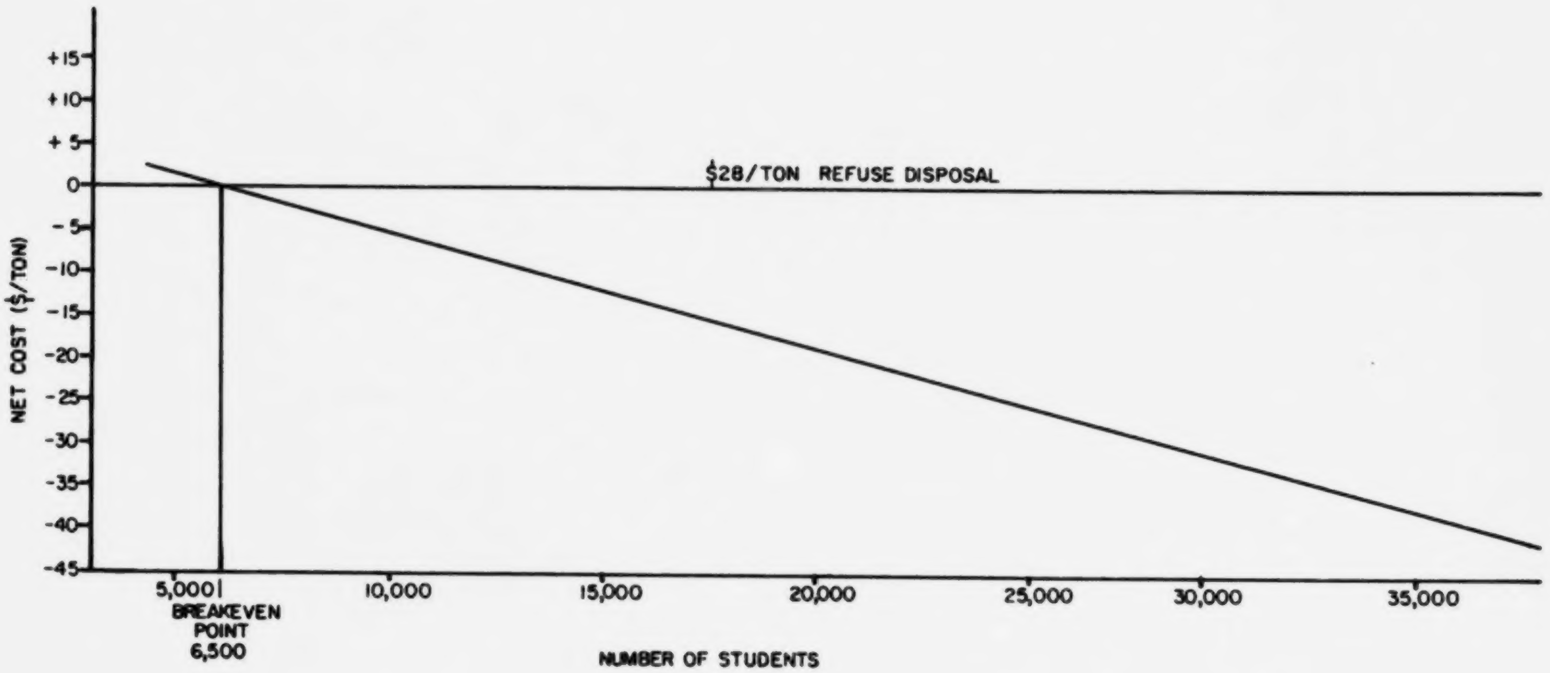

Figure 9. Universities - high-grade paper recovery.

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	87	13.5
(High-Grade-43)		
Plastics	1.5	0.5
Other (e.g., glass)	11.5	----
Total	100	14
		= 7,000 BTU per pound

Average solid waste generation rates are assumed to be 1.5 pounds per employee per day, based on 22 days per month. Therefore, typical generation rates have been identified as 1, 1.5, and 2 pounds per employee per day.

After a preliminary analysis, it was determined that high-grade paper had the highest recycling potential. It was also established that office buildings can utilize energy produced from modular incinerators.

Results of the applicability analysis are shown in Table 25. They indicate that modular incineration, source separation of high-grade paper and a combination of the two systems are feasible for office buildings. The source separation system operates through the use of desk-top containers purchased for each employee.

Periodically, when the container is full, the employee empties the recyclable paper into a conveniently located central storage container. The high-grade paper is collected from the central storage containers by the office maintenance staff. Additional labor required is estimated at 3 hours per employee per month at a rate of $6.50 per hour. Storage costs are also included. Figure 10 shows the breakeven point for high-grade recovery.

Garden Apartments

Garden apartment waste is assumed to be similar to mixed municipal solid waste with the following characteristics:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	35	5.4
Plastics	4.5	1.6

TABLE 25 RESOURCE RECOVERY APPLICABLE TO OFFICE BUILDINGS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 16,000 employees	Yes- $1/10^6 BTU	N/A	7000	8	1 lb/ employee/ day	Paper 87 % Plastic 1.5% Other 14.5%	24 hr/ day	$224	$220
Condition 2 10,670 employees	"	"	"	"	1.5 lb/ employee/ day	"	"	"	"
Condition 3 8,000 employees	"	"	"	"	2 lbs/ employee/ day	"	"	"	"
Condition 4 8,000 employees	"	"	"	4	1 lb/ employee/ day	"	8 hr/ day	$112	$104
Condition 5 5,350 employees	"	"	"	"	1.5 lb/ employee/ day	"	"	"	"
Condition 6 4,000 employees	"	"	"	"	2 lb/ employee/ day	"	"	"	"
SOURCE SEPARATION									
Condition 1 150 employees	N/A	High-grade paper- $55/ton		.075	1 lb/ employee/ day	High-grade paper 43%	70%	$2.10	$2.10
Condition 2 100 employees	"	"		"	1.5 lb/ employee/ day	"	"	"	"
Condition 3 75 employees	"	"		"	2 lbs/ employee/ day	"	"	"	"

MODULAR INCINERATION and SOURCE SEPARATION	One-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 20,000 employees	Yes- $1/10^6 BTU	High-grade paper $55/ton	4480	10 (7 TPD MOD INC)	1 lb/ employee/ day	High-grade paper 43%	24 hr/ day 70%	$280	$248
Condition 2 13,335 employees	"	"	"	"	1.5 lb/ employee/ day	"	"	"	"
Condition 3 10,000 employees	"	"	"	"	2 lb/ employee/ day	"	"	"	"
Condition 4 9,400 employees	"	"	"	4.7 (3.3 TPD MOD INC)	1 lb/ employee/ day	"	8 hr/ day 70%	$132	$118
Condition 5 6,270 employees	"	"	"	"	1.5 lb/ employee/ day	"	"	"	"
Condition 6 4,700 employees	"	"	"	"	2 lb/ employee/ day	"	"	"	"

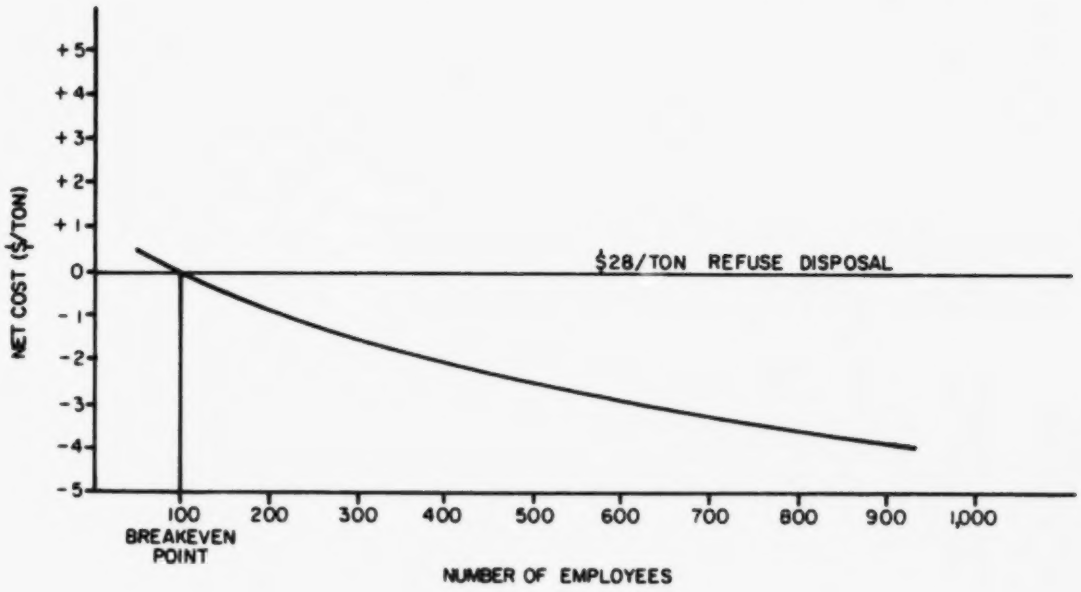

Figure 10. Office buildings - high-grade paper recovery.

Organics	27	1.1
Misc.	11	1.9
Other(e.g.,glass)	22.5	----
Total	100	10.0
		= 5,000 BTU per pound

Generation rates are estimated at 2, 2.5, and 3 pounds per tenant per day. Table 26 indicates the applicability of modular incineration to garden apartments. The only situation in which modular units would be applicable is if the apartment management provides utilities (hot water and/or heat) to the tenants as part of their rent. Also, these units are only marginally feasbible in the case of garden apartments, due to the large number of tenants required to support an incinerator. Since the largest low-rise, garden apartments have about 2,000 to 3,000 tenants, it is seen that modular units are applicable under only a few conditions. Source separation was not deemed feasible from these apartment units due to their small size, unless the system were part of a larger citywide effort.

Trailer Parks

None of the selected systems were deemed applicable to these sources. No market for energy from modular incineration exists and, like garden apartments, these housing developments are too small to support a source separation system unless this effort were part of a citywide program.

Small Cities

Mixed municipal waste from residential and commercial sources has the following characteristics:

Component	Percent in Waste Stream	BTU Value 10^6 BTU/Ton
Paper	35	5.4
Plastics	4.5	1.6
Organics	27	1.1
Misc.	11	1.9
Other(e.g.,glass)	22.5	----
Total	100	10.0
		= 5,000 BTU per pound

TABLE 26 RESOURCE RECOVERY APPLICABLE TO GARDEN APARTMENTS

MODULAR INCINERATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 11,000 tenants	Yes- $1/$10^6$ BTU	N/A	5000	11	2 lbs/ tenant/ day	Paper 35% Misc 11% Plastic 4.5% Other 22.5% Organics 27%	24 hr/ day	$308	$293
Condition 2 8,800 tenants	"	"	"	"	2.5 lbs/ tenant/ day	" "	"	"	"
Condition 3 7,335 tenants	"	"	"	"	3 lbs/ tenant/ day	" "	"	"	"
Condition 4 4,400 tenants	"	"	"	4.4	2 lbs/ tenant/ day	" "	8 hr/ day	$123	$115
Condition 5 3,520 tenants	"	"	"	"	2.5 lb/ tenant/ day	" "	"	"	"
Condition 6 2,935 tenants	"	"	"	"	3 lb/ tenant/ day	" "	"	"	"

Generation rates are estimated at 3, 3.5, and 4 pounds per capita per day. Because city collection services are already provided, a comparison with the existing landfill disposal system entailed a cost of only $7 per ton. When comparing modular incineration with this land disposal system, there is no point below 100 TPD where it would be less expensive. At 100 TPD, modular incineration costs $11.68 per ton. In areas with landfill costs greater than $11.68 per ton, modular incineration would be applicable. Likewise, this approach may be feasible where the value of the recovered energy is greated than $1 per 10^6 BTU. However, an analysis of this system does not appear on the applicability matrix in Table 27.

Source separation was analyzed for newspaper recovery only in either a baled or unbaled state at 30 percent and 50 percent recovery. Ferrous, glass, and aluminum recovery at 30 percent and 50 percent participation were also assessed, as well as two systems that combined recovery of all four materials. Collection and processing was performed as in the scenario described in Section III for source separation. It was determined that source separation of materials is feasible in small cities.

A system combining source separation and modular incineration is feasible, but was not shown in Table 27 as the breakeven point for this system when compared to a $7 per ton disposal fee is well above 100 TPD. At 100 TPD, a combined system recovering all four materials at 50 percent participation would cost $9.69 per ton, and again would be competitive with many landfill disposal systems in various parts of the country. Figures 11 and 12 show the breakeven points for materials recovery.

IMPEDIMENTS TO SYSTEM APPLICABILITY

In analyzing the various waste generators, a number of impediments to applicability of the three selected systems have been recognized. Size (in TPD) of the waste generator is one critical factor. It has been demonstrated that breakeven points for each generator exists, and a minimum size generator is necessary to sustain a viable system. In some cases, such as prisons, modular incineration is marginally applicable because not enough waste is produced to economically compete with existing systems.

Source separation is not a capital intensive system and appears to be more generally feasible for smaller waste generators, where waste stream composition is suitable, than is modular incineration. The cost of modular units is somewhat high for small generators, but as land disposal costs and energy costs continue to increase in the future, this system will become increasingly more attractive at lower capacities.

TABLE 27 RESOURCE RECOVERY APPLICABLE TO SMALL CITIES

SOURCE SEPARATION	On-Site Energy Use	Materials Market	BTU/ lb Waste	TPD	Generation Rate	Waste Composition	Recovery Rate	Existing System Cost/Day	New System Net Cost/ Day
Condition 1 13,600 people	N/A	Newspaper- $40/ton baled	N/A	14	2.5 lb/ capital/ day	Newspaper 9%	50%	$ 29	$ 29
Condition 2 28,000 people	"	"	"	34	"	"	30%	$ 43	$ 43
Condition 1 4,800 people	"	Newspaper- $20/ton loose	"	6	"	"	50%	$ 5	$ 5
Condition 2 12,800 people	"	"	"	16	"	"	30%	$ 11	$ 11
Condition 1 12,800 people	"	Fe-$40/ton AL-$340/ton Glass- $30/ton	"	16	2.5 lbs/ capital/ day	Ferrous 9% AL 10% Glass 13%	50%	$102	$102
Condition 2 25,600 people	"	"	"	31	"	"	30%	$115	$115
Condition 1 11,200 people	" "	Fe-$40/ton AL-$340/ton Glass- $30/ton Newspaper- $40/ton/ baled	"	14	"	"	50%	$116	$116
Condition 2 21,600 people	"	"	"	27	"	"	30%	$136	$136

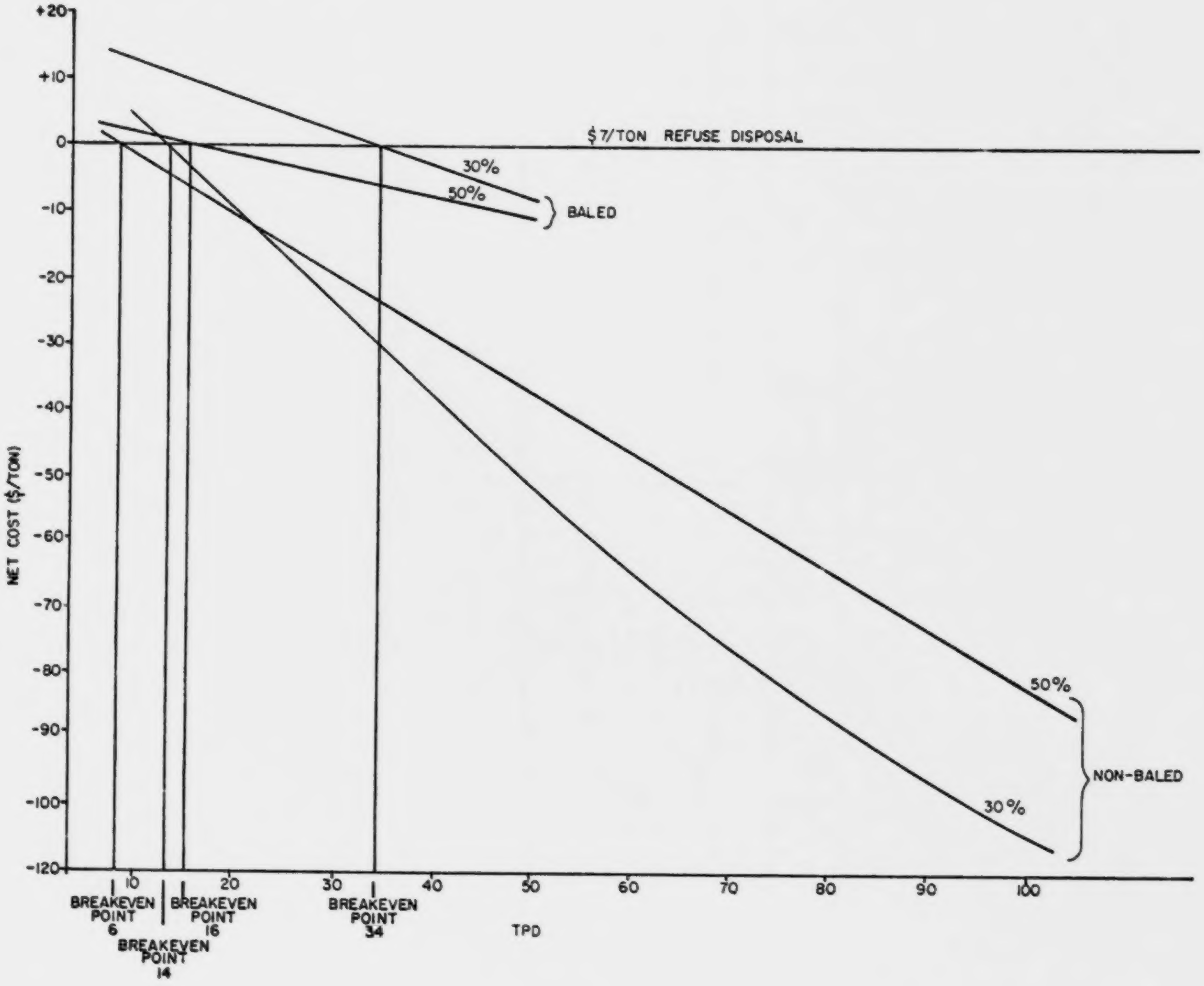

Figure 11. Small Cities - baled vs non-baled newsprint recovery

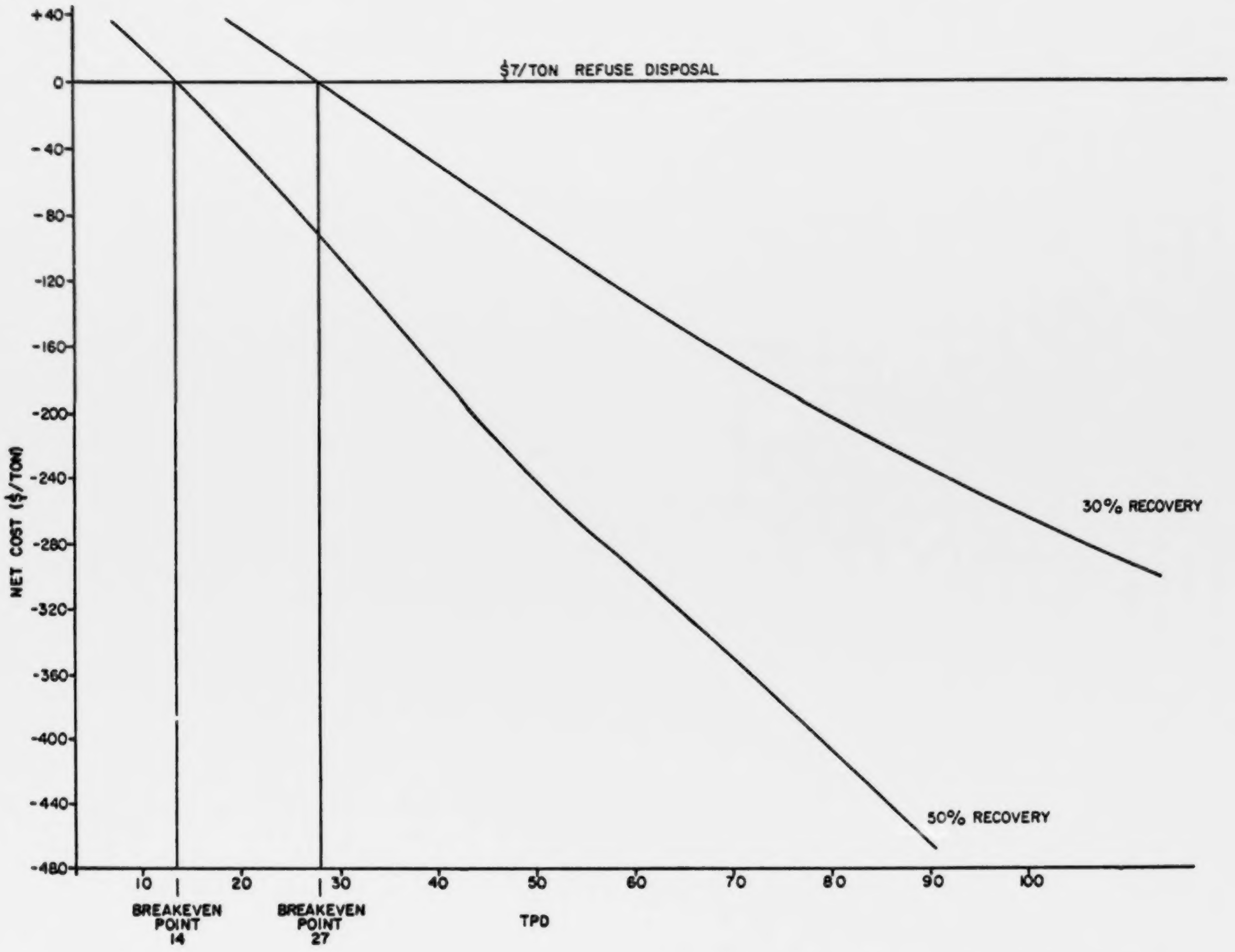

Figure 12. Small cities - newsprint, glass, ferrous, and aluminum recovery.

Availability and volatility of materials markets may be a chronic problem. Uncertainty as to the revenue that can be expected will likely deter decision makers in many situations. The small quantities generated may be more difficult to market and command lower prices per ton than larger quantities of the same materials. If markets stabilize and prices rise there will certainly be more small materials recovery systems in operation.

Energy recovery via modular incineration is limited by the distance the energy can be transmitted. Most systems generate steam that can realistically only be transmitted a few hundred feet. This is usually overcome by locating the incinerator near the energy user. No systems are known to be generating electricity from the steam. This approach could overcome the distance barrier if the value of the energy increases.

Last, present waste handling, storage, and collection practices for the various waste generators are not designed for resource recovery systems. This fact makes implementation of innovative techniques extremely difficult, in many cases, without extensive building modifications or significant higher labor costs. This issue will be dealt with in more detail in the following section.

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SECTION V

RESEARCH AND DEVELOPMENT NEEDS

Four subjects for research and development have been identified. These are:

- Waste characterization studies of small waste generators
- Building design improvements to enhance resource recovery efforts
- Small-scale RDF plants
- Vermicomposting

WASTE CHARACTERIZATION STUDIES

After an extensive literature search, it was determined that relatively little or no information exists on waste composition and generation rates from the small generators of interest in this project, with the exception of hospitals, office buildings and small cities. Data generated for this study were developed by limited, on-site investigations in the Washington, D.C. metropolitan area and telephone contacts with small generators across the country. This waste composition and generation information was assumed to be fairly representative of typical waste generation. However, until detailed waste characterization studies are done for these sources, the data must be considered an approximation. These detailed studies could significantly contribute to increasing the accuracy and utility of the applicability analysis. The concentration of aluminum in a waste stream may be of particular importance. Aluminum is the most valuable material on a cost per pound basis normally recovered. Some of the small generators in this study may be sources of valuable amounts of the material. Potential sources include airports (aircraft maintenance facilities) and institutions.

Currently, managers have little interest in solid waste management except in insuring that wastes are regularly removed. Most of these decision-makers have little knowledge of the amounts of waste generated by their facility, let alone the composition. The existence of waste characterization studies then would serve two purposes:

- Educate decision-makers and encourage their interest in solid waste management in general and resource recovery and waste reduction in particular.

- Improve the assumptions used in determination of applicability and thereby enhance decision-makers' confidence in pursuing resource recovery.

In turn, increased use of resource recovery systems by small generators will significantly improve and possibly expand the state-of-the-art for small-scale and low technology recovery techniques.

BUILDING DESIGN IMPROVEMENTS

Buildings are designed to provide some primary function such as health care in a hospital. Therefore, it is not surprising that ancillary activities, such as solid waste management, receive little detailed attention. Architects and building managers generally plan for traditional waste handling practices which do not facilitate or promote resource recovery. Nor are these traditional plans usually flexible enough to incorporate waste handling changes, thus discouraging recovery in even the most viable situations.

In the case of source separation, a number of problems are typical, including:

- Lack of sufficient storage space

- Lack of maneuvering room in loading dock areas

- Difficulty in collecting and consolidating recyclables.

Current shopping mall design typifies these problems. Commercial establishments are spread out, making consolidation of recyclables over the entire mall difficult. Loading dock space in underground areas is usually not large enough to accomodate extra containers to hold recyclables prior to pick-up. A design option for shopping malls to promote corrugated recovery could include an underground conveyor system connecting the delivery areas of each store. Separated corrugated could be fed into the conveyor through an opening in the floor. The corrugated would be conveyed to a consolidation point where it could be baled or compacted. Another approach might focus on inclusion of modular incinerators with or without energy recovery within buildings.

Areas of recommended R&D effort include:

- Study the impacts of current building design on solid waste management alternatives, especially resource recovery, and recommend design alternatives.

- Identify a waste generator; e.g., shopping center, in the planning stages. Support the design, installation and operation of a resource recovery system and evaluate its technical and economic feasibilities and its impact on waste management and operations of the shopping center.

This type of research would educate architects and building managers and inform them of the role they could play in enhancing resource recovery. At the same time, it would likely serve to stimulate recovery activities of small waste generators.

SMALL-SCALE REFUSE DERIVED FUEL PLANTS

Small-scale RDF plants operating at less than 100 TPD have been previously evaluated as uneconomic. However, this is due to the fact that the systems currently in operation generally have daily capacities in excess of 500 tons. Consequently, the equipment is being underutilized. Small-scale RDF production was included in Section II because the individual components that make up the system are available in the 100 TPD range. However, no such plant has been assembled.

R&D efforts could concentrate in the following areas:

- Demonstration of the technical feasibility of and RDF operation at 100 TPD.

- Investigations into problems associated with the storage and transportation of RDF from these small plants.

- Design of RDF processing equipment in the 100 TPD range that combines the functions of two or more units.

- Determine market demand for RDF in the quantities generated from 100 TPD plant. These would be markets external to the waste generator.

VERMICOMPOSTING

Vermicomposting is the feeding of organic waste to earthworms. Specially designed and managed facilities must be used. A humus-like material, which can be used as a soil conditioner, is the primary product. Excess worms also can be harvested and sold.

Activities to date have tended to concentrate on the feeding of agricultural wastes to worms. This material is homogeneous and easily digested by worms. Several tests have been made with municipal solid wastes. No commercial-scale operations were functioning when this report was prepared. However, a project was scheduled to begin using the wastes from the Chester County Prison Farm in Pennsylvania, (Personal communication. Robert Kohe, GTA, Incorporated, Wilmington, Delaware. December 27, 1978).

A vermicomposting facility requires special design and operational considerations. Lechate control and protection against worm predators (e.g., moles and certain species of birds) are the major design features which need to be factured into this approach to resource recovery. The basic operation of a vermicomposting system involves five steps:

Step 1: Biodegradables are separated from mixed municipal waste through either source separation or mechanical processing and shredded.

Step 2: The shredded biodegradables, including paper, are spread in windrows approximately 3 feet wide and no deeper than 18 to 24 inches.

Step 3: The waste is digested by the earthworms at a rate of approximately 1 to 2 pounds per pound of earthworms per week.

Step 4: At regular intervals additional shredded waste is laid on top of the windrows. The earthworms feed from the top of the piles and deposit castings at the bottom.

Step 5: Castings are periodically removed, screened, and sterilized and may be sold as potting soil or compost. One company currently is selling worm castings as potting soil for a retail price of $1.00 to $2.00 per gallon(1).

The relative simplicity and claimed total lower capital and operating costs vis-a-vis mechanical resource recovery are the major advantages of vermicomposting. Furthermore, as with any resource recovery process, vermicomposting will reduce landfill requirements. The extensive need for land is the primary drawback to vermicomposting. About one acre is needed for each 8.25 tons of waste being composted (2). The land; however, is only used as a surface for the vermicomposting; thus, can be reused as wastes are converted and removed. A facility, which receives 100 TPD of municipal solid waste, would need about 42 acres for the worm windrows. This figure is based on the following assumptions:

- 70 percent of the incoming waste is biodegradable
- the worms will digest seven to eight tons of waste per acre per week

- the facility receives waste five day a week

A number of areas require further research (1):

- Determining optimal windrow configurations
- Determining feasible temperature controls for cold climates
- Assessing optimal moisture levels
- Determining optimal pH levels
- Establishing ideal material density
- Determining best population density and nutrient profile
- Assessing the effects of contamination from toxic materials
- Assessing public acceptance of the process and the resulting product

It appears that this type of system may have applicability to certain small waste generators, such as universities and prisons, where organics are easily kept separated from the mixed waste stream. Small cities also may be interested in this system's potential. However, further research also is necessary to determine the feasibility of a continously operating system on a commercial scale. In addition, operating requirements, capital and operating costs, and product quality need to be assessed.

REFERENCES

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APPENDIX A

CONVERSION TABLE FOR METRIC UNITS OF MEASURE

WEIGHT

1 pound = 454 grams

1 ton = 907 kilograms = 0.907 metric tons

LENGTH

1 inch = 2.54 centimeters

1 mile = 1.61 kilometers

AREA

1 square foot = 0.093 square meters

1 acre = 4,047 square meters = 0.405 hectares

VOLUME

1 gallon = 3.79 liters

1 cubic yard = 0.765 cubic meters

ENERGY

1 British Thermal Unit (BTU) = 1,054 joules

1 therm = 1,000 BTUs = 1.05 x 10^6 joules

1 kilowatt-hour = 3.6 x 10^6 joules

MISCELLANEOUS

1 mile per gallon = 0.425 kilometers per liter

1 BTU per pound = 2.32 joules per gram

APPENDIX B

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APPENDIX C

SMALL-SCALE AND LOW TECHNOLOGY RESOURCE RECOVERY OUTSIDE THE UNITED STATES

INTRODUCTION

In order to make the project as comprehensive as possible, information was sought concerning approaches to resource recovery as practiced in countries outside the United States. The primary method of obtaining this information was attendance at the First World Recycling Congress and Exhibition held in Basel, Switzerland in March 1978. Gary Mitchell, the SCS project manager, was the delegate to the Congress. In addition to attending the technical sessions and visiting the equipment exhibition, personal contacts were made with authors of papers associated with small-scale or low technology approaches. These contacts led to further interchange of information via correspondence.

PURPOSE OF THE CONGRESS

The purpose of the Congress was to bring together knowledgeable authorities in the area of waste recovery and recycling to discuss the most recent developments and approaches to the recovery of reusable materials and energy, and approaches to the recycling of recovered waste materials. The three-day conference attracted over 400 delegates. Some 45 papers were presented with the authors representing 15 countries from all continents with the exception of South America.

The associated equipment exhibition provided for the display of technologies and sytems for the recovery of recyclable materials. Exhibitors representing processes and hardware for the recovery of and reuse of industrial manufacturing wastes as well as recovery of materials and energy from municipal refuse were present.

IMPRESSIONS AND GENERAL COMMENTS

Overall, the Congress and Exhibition were oriented more heavily toward recovery and recycling of industrial wastes than toward like activities associated with post-consumer wastes. Particular emphasis was placed on the in-the-plant or trade recovery and reuse of wastes from the plastics, glass, and textile industries.

However, a number of papers were presented in the area of municipal waste resource recovery. Virtually all of them were directed toward recovery of materials or energy from the mixed waste stream with little emphasis on source separation of materials. Specific areas that were covered include:

- Magnetic separation
- Air classification
- Recovery of tin cans and other materials from incinerator residue
- The use of earth-worms as a solid waste management technique

Likewise, the equipment exhibition was oriented toward the reprocessing of industrial wastes such as plastic scrap and high technology, high volume systems to recover resources from municipal waste. An interest in the recovery of post-consumer glass; however, was displayed. The European Glass Container Federation had a display including examples of "Bottle Banks" used in England and Europe as drop-off containers for source separated glass.

The impression received after talking to speakers and exhibitors was that little source separation and separate collection is conducted in Europe and elsewhere in the world. The interest in incineration with heat recovery, particularly in Europe, likely precludes any activities to remove paper from the waste stream. Those speakers commenting on source separation and low technology systems noted that these approaches were generally not found outside the United States. These authors indicated that either disposal was relatively inexpensive, or was accomplished by incineration, or an extensive scavaging system operated (this latter approach is prevalent particularly in Asia).

SPECIFIC FINDINGS

Copies of all papers presented at the Congress were obtained. Citations to these publications have been included in the bibliography under the appropriate subject.

Personal contact was made with authors of three papers particularly applicable to the small-scale and low technology study: Joseph E. Greevy, the Executive Director of Keep Ireland Beautiful, presented a paper on recycling and reuse of waste in the Irish Republic. He noted the interest in glass recovery in Ireland, primarily using drop-off containers or recycling centers. He pointed out that there was no high-grade paper separation in any of the office buildings in Ireland. He further noted the need for encouragement and even requirements on the part of the Irish government to recover recyclable materials. It was his opinion that the Irish government should formulate guidelines similar to the EPA's Material Recovery Guidelines (40 CFR 246).

Dr. Michael Connor of South Africa gave a paper on the applicability of modern technologies for recovering energy and materials from urban waste to developing countries, using three developing nations; India, Kenya, and South Africa; as case studies. He pointed out that the most feasible resource recovery system for developing countries is composting. The soil fertility in many of these areas is rapidly decreasing and, due to a lack of organic material, the land is producing less.

Dr. Connor noted that most developing countries have some of the necessary prerequists for the implementation of low technology systems; i.e. an interest in creating jobs and a relatively large available labor force willing to work for extremely low wages. However, he pointed out that most developing nations are doing little in the way of resource recovery because they have much higher priority needs than improved solid waste management.

An interesting aspect of resource recovery was discussed by Basil A. Rossi from the Philipines. He gave a paper on recycling and non-waste technology in Asia. Mr. Rossi described the presence of scavenging in Asia and many developing countries noting that some 2,000 people in Manila make their living by manually separating recoverable materials at the land disposal site serving the city. Mr. Rossi was a proponent of the use of earthworms in the management of urban solid waste. He felt that Asia had a high potential for low technology resource recovery by noting the importance of resource conservation in many Asian nations due to the lack of natural resources. The fact that wages in many Asian countries are very low, averaging about $2 per day, also encourages labor intensive activities.

At the equipment exposition, a display was presented by the Warren Springs Laboratory in England. This government-supported laboratory had built a pilot-scale, high technology system for the recovery of materials from mixed municipal refuse. The pilot system operated at the rate of four tons per hour and separated mixed glass, aluminum, ferrous, fluff RDF, and a residue. It proved technical, but not economic feasibility at the designed throughput. The pilot system is being dismantled prior to the construction of a full-scale (500 ton per day) operation. Representatives of Warren Springs indicated that the pilot-scale operation (32 TPD in eight hours) was not economically feasible and that derating the full-scale system would not be economically attractive either. The latter approach could be accomplished by operating the full-size (500 TPD) equipment to process only 100 TPD. A similar opinion about the economics of small, high technology systems was expressed by other exhibitors of high technology systems at the equipment exposition. However, the representatives of Warren Springs knew of the existence of some separate newsprint collection activities in cities near their laboratory.

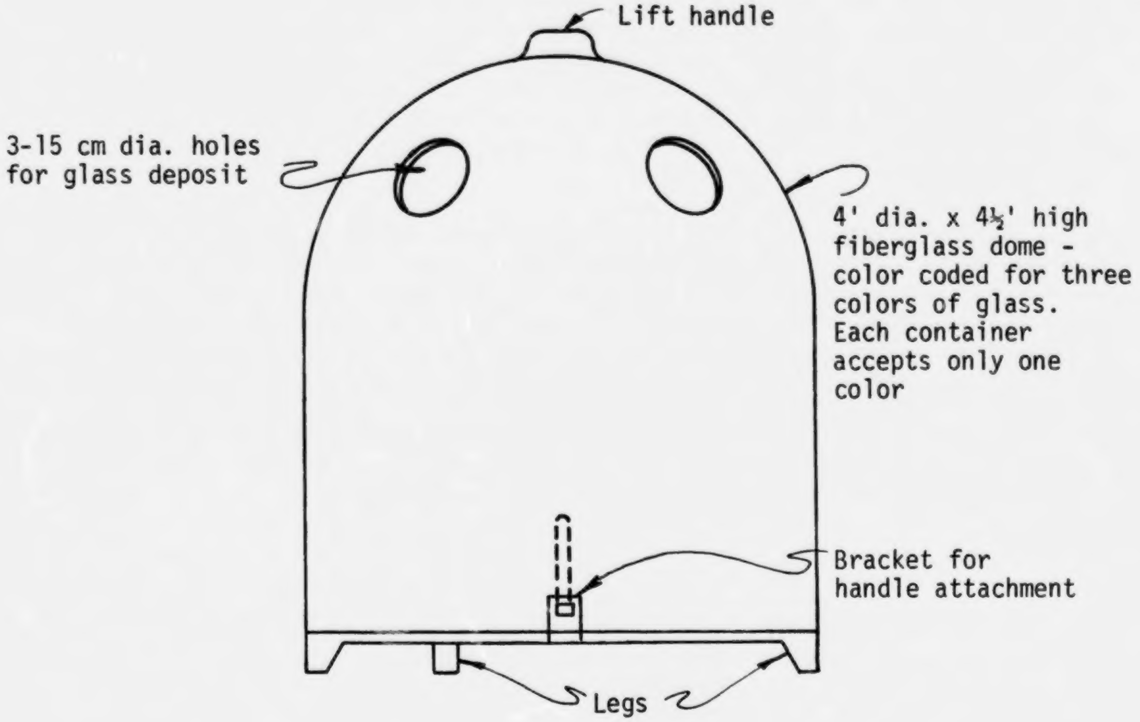
Brochures and literature on various high technology systems or subsystems of those technologies applicable to small scale operations were obtained at the Congress. These systems included magnetic separation and an Italian energy recovery system which generates both hot water and electricity from various fuel sources. One of the fuel sources noted was methane gas generated from the decomposition of organic material, including refuse and sludge.

Information was also obtained about uniquely designed drop-off containers for source separated glass. These dome shaped fiberglass containers are popular in Germany and other parts of northern Europe. See Figure 13. They are colored-coded for the color of glass to be received and have 15-centimeter holes in the top to discourage the depositing of oversize containers of refuse. When full, the containers are lifted by a truck-mounted crane and emptied into appropriate bins on a truck. The glass container is then returned directly to its location with the truck moving on to service other containers.

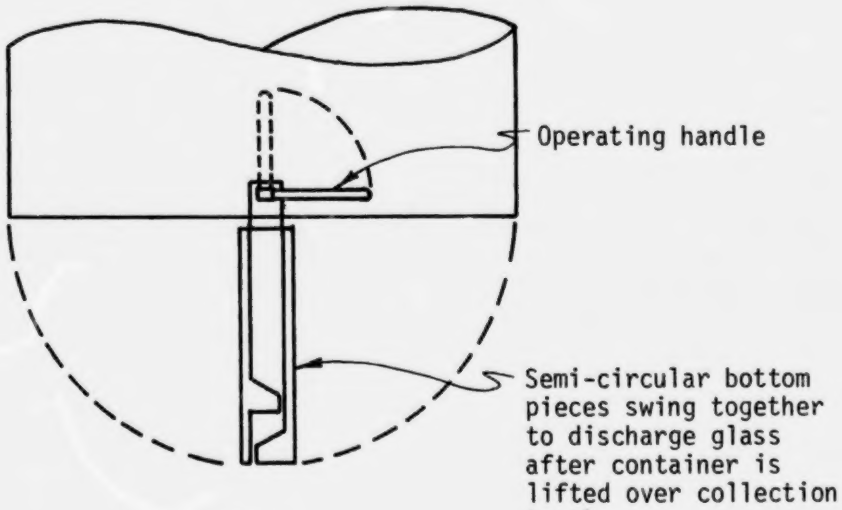
CONCLUSION

No innovative or unique approaches to resource recovery meeting this project's definitions of small-scale and low technology were identified at the Congress. This certainly does not preclude the existence of such systems outside the United States. However, lack of their presence at this forum indicates that the likelyhood of their existence is slim. This conclusion was fortified by the predominance of papers from non-U.S. authors that focused on high technology and industrial resource recovery.

Thus, it appears that most of the interest in the development and implementation of small-scale and low technology resource recovery is in the United States. Likely reasons for this situation include increasing (and high, relative to most other countries) costs for acceptable land disposal and this country's interest in technological solutions to as many problems as possible. Therefore, it is suggested that near-term future information collection efforts focused on foreign small-scale or low technology resource recovery be limited to the information entering this country in the form of publications and representations of foreign governments and equipment manufacturers and users.


Lift handle
3-15 cm dia. holes for glass deposit
4' dia. x 4½' high fiberglass dome - color coded for three colors of glass. Each container accepts only one color
Bracket for handle attachment
Legs

CLOSED


Operating handle
Semi-circular bottom pieces swing together to discharge glass after container is lifted over collection truck

OPEN

Figure 13. European Drop-Off Container for Source Separated Glass

APPENDIX D

SUMMARY OF INFORMATION FROM EQUIPMENT MANUFACTURERS INCINERATION WITH WASTE HEAT RECOVERY

MANUFACTURER	DESIGNATION	CAPA-CITY (lbm/hr)	WEIGHT (TONS)	RATING (BTU)	COST		REMARKS
					CAPITAL	OPERATE	
Alessandro Lolliwi	no heat recovery						
Babcock & Wilcox							
Basic Envir. Engr.	Model 300						
Bayco Ind.	GR and PR 300			1800 lbs			water wall: > 300 TPD
Besser Wasteco	DCR-2	100-300 500	32.5	1500 MM/HR			
The Bethlehem Corp	Model 80		6.4	27.6			suspension burning co-firing w/coal custom units
Brule	custom		5-27 tons	2-12			
Burn-Zol	272	375-520$^+$		3			custom units
CE Air Preheater	no heat recovery						
CE Combustion Engr.	no heat recovery						
Certified Incinerator	no heat recovery						
Clean Air Inc.							
Control/Sunbeam	Model A-48	12500 1TPH	40	62.5 17			have designed 75PO units
Combustion Power Inc.	CPU-400	8TPH		10^3KW	15x10^3/T/D	$6/ton	economic > 200 TPD
Combusto Pak	no heat recovery						
Consumat Systems	H-760	1.25TPH	45	10 ton/ton			have hosiptal systems
Dispatch Oven Co.	no heat recovery						
Driall, Inc.	no heat recovery						
Econo Therm Corp.	Plo-400	400	18.3	3.2			
Energex Limited	no heat recovery						
Energy Cube	RDF (no data)						
Energy Dynamics	no heat recovery						
Environmental Control Prod	2500 T	2000	27	11.4			
Envir. Tech. Div.	no heat recovery						
Kellog/Mann Corp.	non-ferrous recovery	1600					
Kelly Co., Inc.	1280	$.8^T$	17	3.2	33000 127500	.03/16	data not responding
Jarvis Incin. Co.	no heat recovery						
Midland Ross Corp.	no heat recovery						
Morse Boulger Inc.	no heat recovery						
Nichols Engr.	no heat recovery						

INCINERATION WITH WASTE HEAT RECOVERY

MANUFACTURER	DESIGNATION	CAPA-CITY (lbm/hr)	WEIGHT (TONS)	RATING (BTU)	COST		REMARKS
					CAPITAL	OPERATE	
O'Conner Engr.		75TPD		$23x10^3$#	$22-35x10^3/ 3		data not responsive
Oritron Corp.	custom	60TPD		7720#			Europe (mostly large scale)
Plibrico Co.	no heat reocvery						
Peabody Inter. Corp.	solid fuel burners			40			
Prenco	no heat recovery						
Pyro Cone							
Rust Engr. Co.	custom						mostly large scale
Shirco, Inc.	no heat recovery						
Smoka Crol, Inc.	Model 2000	2000		12.3			
Tesco	no heat recovert						
Thermal Processes Inc.	no data						
Thermal Research	no heat recovery						
Thermo Electron	no data						
The United Corp.	no heat recovery						
UOP Corp:	custom	132TPD		27.8			other data non-responsive
W.A. Kutrieb Inc.	no heat recovery						
Watson Energy Sys.	no data				$25MM		
Zurn Ind. Inc.	no heat recovery on package units						
C.E. Barlett-Snow	Modular						
Comtro	Modular						
Giery	Modular						
Lamb - Cargate	Modular						
Scientific Energy Engineering	Modular						
Washburn & Granger	Modular						
Ci Co	Modular						
Federal Incinerator, Inc.	Modular						
Simonds Company	Modular						
U.S. Smelting Furnace Company	Modular						

BALERS

MANUFACTURER	DESIGNATION	CAPA-CITY (lb/hr)	BALE SIZE in/in/in	WEIGHT (lbm)	hp	COST ($)		REMARKS
						CAPITAL	OPERATE	
American Baler	Mobil Mite 42M		42/30/20	1775	5			horizontal
American Baler	Econo-matic 3621		36/20/24-34	1500	.3			vert./down stroke
American Baler	Economy 127		54/27/27-5	1250	10			vert./up stroke
American Baler	Economy 54-36		54/48/30	5100	10			vert./down stroke
American Designed	HL-600		60/48/30	5350	5			vert./down stroke
American Solid Waste	HRB - SWC 1	26000	64/45/32	51000	100			horizontal/auto
Balemaster	5440		54/40/31-40	5000	7.5	6000		vert./down stroke
Balemaster	360		30/42/60	6600	15	7000		horizontal/portable
Balemaster	142		30/20/42			4000		horizontal
Compaction Devices	Mr. Packer Lu501		29/29/30	1500	5	32500*		vert./down stroke
Consolidated Bailing	HUS-16		24/28/	11300				vert./ up stroke
International Bailer	NA-500 S		42/30/30		10			horizontal
International Bailer	SP-72		72/30/43		10			vert./down stroke
International Bailer	MI-30		30/16/28		3			vert./down stroke
J.A. Freeman & Son	36" Mini		20/36/24	1500				vert./down stroke
Legemann Bros.	245-1	2000	40/30/60	45000	40			horizontal
Muncher Corp.	Model 36		36/24/30	1830	3			vert./toggle
National Baling Press	HY-36A		36/24/18-30	2300	5			vert./down stroke
Philadelphia Tram-rail	Model 1800		30/48/24-36	4200	5			vert./down stroke
The Union Corp.	Model 4830		30/48/32	3900	7½			vert./down stroke
Weathershield Corp.	LP 25M	2400	44/28/60	11000	10			horizontal
Enterprise Corp.	3036 HWW		30/36/VA8	22000	25			
Enterprise Corp.	3072-6HD			7500	10			
Tubar	Hydraulic Baler		30/20/42	700	10	4995		vert./down stroke

SHREDDERS

MANUFACTURER	DESIGNATION	CAPA-CITY (lb/hr)	WEIGHT (lbm)	hp	MIN SIZE (in)	COST ($)		REMARKS
						CAPITAL	OPERATE	
Allis Chalmers								220 tons/hour
Amer. Bulky Waste	50TF Shredder	3-6	11000	75-150	164/145/100			
Amer. Pulverizer	we- 8	2000-10,000						aluminum also comes in
Bale master	1000 C		11000	30				paper waste material
Bencorp Industries	2436	10000	38000	7.5	44x74x31			normal household waste
Blower Application Co.	Piggyback shredder			40	72x48 feed			paper
Eidal	100-B	5000	15100	100				hospital use
Enterprise Co.	4484 C CONV	6000/24000	23000	75-250	112/126/ 72			
General Binding	conveyor 400	2500	880	4	33x29x44			paper shredder
Gruendler								shown but no data
Hammermills, Inc.								100 Biv
Hazemag USA								no data
Heil	series 42	20000		200				
Jeffrey Mfg. Co.								90 tons/hour
Kleco Shredder Sys.	Az 40		4000	2-20	17x38x99			
L.A. By Products Co.								> 80 tons/hour
Miller Mfg. Co.								no data
Mitts & Merril								brush chipping
Montgomery Ind.								
Multinational Res. Rec.								2120 tons/day
Newall Ind.								only 260 ton/day
Penn Crusher Corp.	51 30 30	4000-10000	6000	60	25x35x79			
Prodeva Inc.	320 + 325		1025-1250	20-25	75x54x79			
Rexnord								
Saturn	36-22		6500	50		25,500		hospital/light industrial
Tele-Com INd. Corp.	U-122	1400	2100	7.5	72x30x32			6 month warranty
Tubar	T320/T325 plast and can shredder		1025-1250	20-25	51x30x72	2635-2970		used by hospitals
Williams Patent Crush	F paper shredder							no data
WW Grinder Corp	F22M	600-36800	820	530		1219		all purpose shredder

AIR SEPARATORS

MANUFACTURER	DESIGNATION	CAPA-CITY (lb/hr)	WEIGHT (lbm)	hp	MIN SIZE (in)	COST ($)		REMARKS
						CAPITAL	OPERATE	
Aenco, Inc.								no data
Allis Chalmers								no specs
Rader Pneumatics	Model "EF" Feeder		1125		14x18	2548		wood chips
Raytheon Co.	"Prototype"	8000						under construction
Tripel S. Dynamics								>25TPH
Williams								no specs
		MAGNETIC SEPARATORS						
Dings Magnetics								no specs
Envirotech	re spearator	40,000	28700	37	16'x10'x 10'			no specs
Eriez Magnetics	A	1000 cuft/hr	180					
Stearns Magnetics								no specs
United Farm Tool - Miller Division								
		PYROLYSIS						
Acme Trading & Supply								
Andco. Inc.								
		COMPOSTING						
Fairfield Service	digestor process	100 tons	--	--	--	2,750,000	18	

APPENDIX E

COMPONENT DESCRIPTIONS

The components of resource recovery systems are described in detail in this appendix. Most of these components are commercially avaiable. Some, however, have yet to be proven in commercial-scale operation. These components are:

- acid hydrolysis conversion units
- air classifiers
- aluminum magnetics
- balers
- composting
    - aerobic
    - anaerobic (methane digestors)
- froth flotation units
- magnetic separations
- modular incinerators
- pyrolytic units
- shredders
- trommel screens

Appendix D lists manufacturers of some of the above items. Some of the components are available in very small capacity sizes (under one ton per day) up to large capacity sizes (several hundred tons per day). The manufacturers should be contacted to determine the sizes and operating characteristics of their equipment.

Acid Hydrolysis

An interesting variation of the methane digestion process produces yeast and is known as acid hydrolysis. A number of products could potentially be generated from the yeast produced by this system including glucose alcohol and other organic chemicals. The primary product, yeast, can also be utilized as an animal feed supplement without further processing.

The waste fed acid hydrolysis system is essentially a methane digestion system with digestion replaced by hydrolysis. The prepared waste material is innoculated with a strain of bacteria which can rapidly multiply and convert the substate to biomass.

Acid hydrolysis conversion of waste material is still in the experimental and pilot facility stage of development. Research being conducted by a number of investigators is aimed at determining the most efficient types of bacteria for different types of waste, innoculation rates, temperature and moisture influence as well as a host of other operating variables.

Air Classifier

The purpose of air classification is to separate mixed materials based on their physical properties, including weight, size, shape, and aerodynamic characteristics. Air classification is considered a significant process in the recovery of materials and energy from mixed municipal solid waste. In addition to solid waste processing, air classifiers are used in numerous other applications such as the separation of peanuts from their shell (1).

Air classifiers use the principle of sedimentation to separate materials. This principle applied here states that relatively heavy material is unable to overcome gravity and will fall, whereas, lighter materials will be carried upward. Although weight is the primary factor affecting separation, the physical properties mentioned above, size, shape, and aerodynamic characteristics may cause some particles of a material to rise while others drop.

Air classification typically takes place after shredding. At this point, the incoming refuse is divided into a light and heavy fraction. The light fraction is primarily organics, which can be processed into a solid, liquid, or gaseous fuel. Some inorganics, primarily glass, are carried into the light (fuel) fraction. This increases the ash content of the fuel (2). The presence of inorganics in the light fraction also can cause problems in combustion and increase the cost of residue disposed after burning (3). These problems could be eliminated by lowering the velocity of the air stream. However, even with these problems, revenue is maximized if the air classifier is run at a high velocity to recover the maximum amount of combustible materials. Processing of the light fraction, such as trommeling, helps to remove inorganic grit after air classification.

The heavy fraction of the incoming waste contains primarily glass and metals. Removal of the organics during air classification aids in the recovery of the materials in the heavy fraction. The inorganics, which become entrained in the light fraction in air classification, represent a loss of recoverable material. Even so, air classifier efficiency is maximized by operating the system at high velocity.

An important aspect of air classification is de-entrainment. The light fraction of waste must be separated from the air stream after classification. This process usually is done by use of cyclones which cause the air stream and the entrained waste to move in a circular pattern. The joint action of centrifugal force and gravity causes the material to move to the outside of the cyclone and fall to the bottom (4).

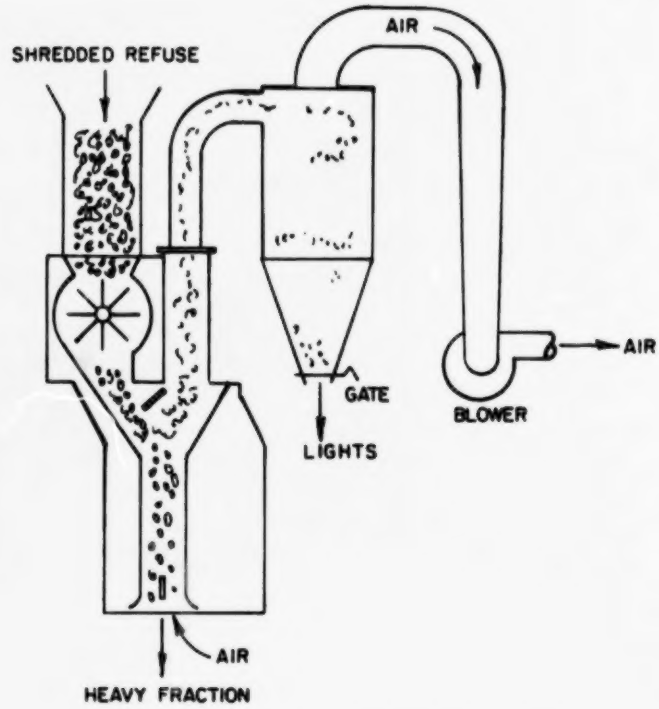
There are four basic types of air classifiers used to process refuse for resource recovery; (1) vertical, (2) horizontal, (3) rotary, and (4) air knife.

Vertical air classifiers have been installed in Ames, Iowa, Chicago, Illinois, Milwaukee, Wisconsin, New Orleans, Louisana, and Lane County, Oregon. In each system shredded waste is fed into a vertical chamber through which air is either blown or drawn. The particles which rise are processed into a fuel product. The heavy materials fall and become input for recovery process to reclaim metals and glass, Figure 14.

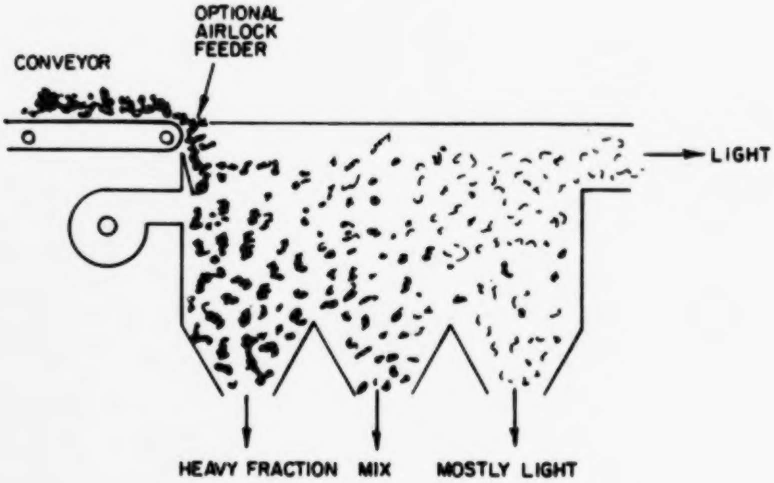
Horizontal air classifiers have been developed by both the U.S. Bureau of Mines and Boeing Engineering and Construction. In both processes, processed refuse is fed into an air classifier where it meets a horizontal air stream. The heavier materials drop through the stream; while the lighter materials become entrained in the horizontal air stream, Figure 14. The Boeing process has been installed in a recovery system currently undergoing shakedown in Tacoma, Washington. The prototype for this system was tested successfully at a rate above 400 TPD. The capacity of the Tacoma plant is 500 TPD (5). This facility was designed by Boeing.

Raytheon Service Company and AENCO (Cargill Company) have both developed rotary drum classifiers. This classifier has been tested, but no commercial applications have taken place. The input refuse is fed into the rotary drum near the lower end. The heavy materials being unaffected by the air stream are discharged at the lower end. The lighter materials move up the drum where they are separated from the air stream, Figure 15. The advantages claimed for rotary drums are; (1) lower air velocity, (2) longer retention time in the classification chamber, (3) a tumbling action to free entrapped particles, and (4) less impact on performance due to feedrate surges (6).

The air knife is a different approach to air classification than the other systems described. An air knife provides a blast of air, which seeks to separate lighter objects from the waste stream. In operation, air knifes are being used: (1) in conjunction with another type of air classifier to breakup materials that have been adhered together (Figure 15), and (2) to separate organics from non-ferrous metals and light aluminum from other non-ferrous metals.

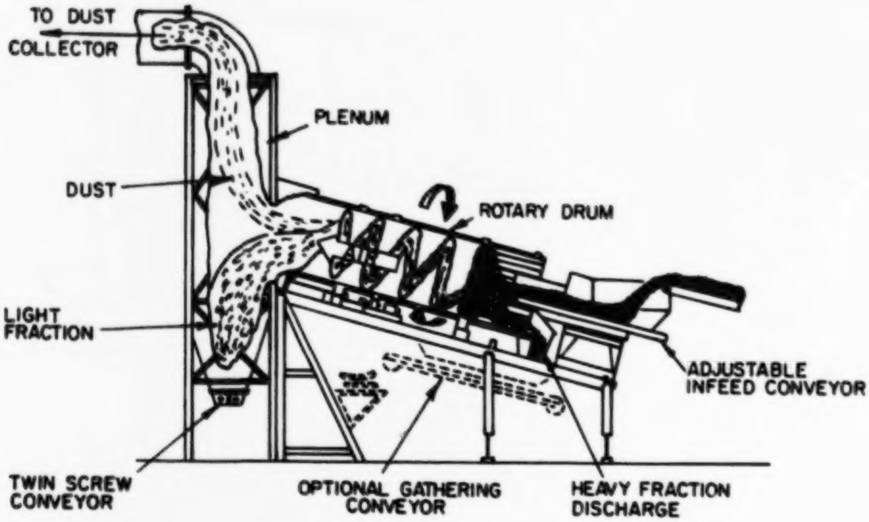

SHREDDED REFUSE
AIR
GATE
LIGHTS
AIR
BLOWER
AIR
HEAVY FRACTION

Vertical Air Classifer

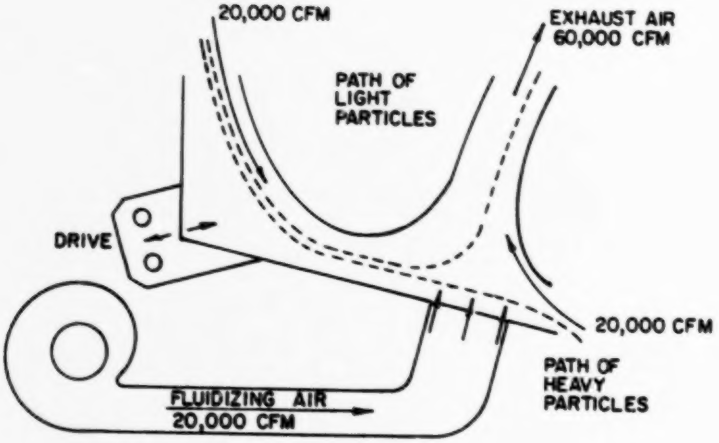

OPTIONAL AIRLOCK FEEDER
CONVEYOR
LIGHT
HEAVY FRACTION
MIX
MOSTLY LIGHT

Horizontal Air Classifer

Figure 14. Air Classifer - Vertical and Horizontal


TO DUST
COLLECTOR
PLENUM
DUST
ROTARY DRUM
LIGHT FRACTION
ADJUSTABLE INFEED CONVEYOR
TWIN SCREW CONVEYOR
OPTIONAL GATHERING CONVEYOR
HEAVY FRACTION DISCHARGE

Rotary Drum Air Classifer


20,000 CFM
EXHAUST AIR
60,000 CFM
PATH OF LIGHT PARTICLES
DRIVE
20,000 CFM
PATH OF HEAVY PARTICLES
FLUIDIZING AIR
20,000 CFM

Air Knife

Figure 15. Rotary drum air classifer and air knife

Aluminum Magnets

An aluminum magnet is a generic term for a recovery unit designed to separate nonferrous metals from nonconducting materials. The basic principle of eddy current separation involves the generation of a moving electromagnetic flux field that sets up a repulsive force in conductors (nonferrous metals) that repels them from the field. The repulsive force is a function of weight, shape and material. Reportedly, systems are under development which will be able to separate aluminum from other non-ferrous metals (7).

Combustion Power Company, Occidentied Research, and the Raytheon Company have developed nonferrous separation systems using eddy currents (8). An eddy current separator is in operation at Ames, Iowa. Separators are in shakedown at Baltimore County, Maryland, New Orleans, Louisana, Milwaukee, Wisconsin, and Hempstead, New York. Two recovery systems currently under construction will use aluminum magnets, Monroe County, New York, and Bridgeport, Connecticut, (Personal communication. Joseph Duckett, National Center for Resource Recovery, Inc., Washington, D.C. July 25, 1978). The operating experience of aluminum magnets is still limited to consider them to be proven technology.

A 100 TPD separation system would cost about $30,000. On the basis of an 8-hour day, 260-days per year, the cost of operation including amortization, would be $2.50 per ton. The revenue derived will depend on the quantity of aluminum cans in the waste stream. For example, if aluminum cans comprise one-half percent of discards and 80 percent are recovered, the revenue would be $1.36 per input ton at $340 per ton of aluminum cans.

Composting

Composting is the biological decomposition of organic solid waste under controlled conditions. The simpler the organic structure of a waste, the wider the variety of bacterial species to which it is subject to attack; thus the more rapid the rate of decomposition. Newsprint, for example, is a complex organic material and; therefore, is highly resistant to microbes.

Modern municipal solid waste contains too few simple organic wastes (e.g., food waste) to produce a good quality compost or even for composting to be practical. Garbage disposals and packaged food have contributed to the reduction of simple organic wastes. The poor quality of municipal solid waste as measured by the carbon-nitrogen (C-N) ratio can be improved by the addition of sewage sludge, or other materials high in nitrogen. The addition of such materials creates a mixture with a favorable C-N ration.

Compost projects typically are classified by oxygen use. Aerobic composting takes place in the presence of oxygen and is the type commonly associated with the term composting. Anaerobic composting, which occurs in the absence of oxygen, generally is referred to as methane digestion. The characteristics of aerobic composting are high temperature, the absence of foul odors, and more rapid decomposition than anerobic decomposition. Anaerobic decomposition has the opposite characteristics. The advantage of anaerobic composting are: (1) the process requires a minimum amount of attention, (2) the rate of nitrogen loss is lower than with aerobic composting, and (3) methane gas is produced during decomposition (9). These two approaches to composting are described later, as well as the economics of operation.

Composting, like any process, is controlled by various parameters. These parameters are set by the microbes, which decompose the waste. The parameters are: (1) a suitable microbe population must be present, (2) the rate and efficiency of the process are functions of the rate and efficiency of microbial activity, (3) the capacity of an operation is limited by the size and nature of the microbe population, (4) the subsrate subject to composting must be organic, and (5) environmental factors are of key importance.

The environmental factors of key importance are moisture content, temperature, hydrogen-ion (pH) level, and oxygen level. The closer the moisture content is to 100 percent the better the rate of composting. As the moisture content approaches 100 percent, microbe activity increases. Anaerobic composts operate at a 100 percent moisture level. The typical aerobic compost operation functions at about 80 percent moisture content. A moisture level below 50 percent adversely affects microbe activity (10).

Compost temperatures are divided into two categories, mesophilic (temperature range 15-25°C) and thermophilic (temperature range 45-65°C). Bacteria are claimed to be most efficient in the mesophilic range. The pathogens, weed seeds, and fly larve in wastes are killed, however, by the thermophilic temperatures. In general, compost will be processed at both these levels some of the time. Anaerobic composting tends to operate more frequently on the lower temperatures because of lower microbial activity. Because of the lower operation temperature, external heat must be used to maintain microbe activity in cooler climates.

Microbe activity can be adversely affected by an acidic pH level. Below a pH of 6.7 composting proceeds with decreasing efficiency. Beyond a pH of 6.2 waste decomposition ceases. Control of acidic pH typically is accomplished by the addition of lime. Lime, however reduces the nitrogen content of the compost. Recently, sodium bicarbonate, an alkali, has been found to more effectively control pH. In either case, the addition of control substances can be expensive.

Another environmental parameter is the oxygen level. The absence of oxygen in an aerobic process or the presence of oxygen in an anaerobic system will have detrimental effects on the microbes involved. In an aerobic operation, oxygen is introduced into the compost either by frequent turning or by forcing air through the compost. Anaerobic digesters require a sealed enclosure which excludes oxygen. The enclosure also aides in the collection of methane.

Aerobic Composting--

A humus like material whose chief use is as a soil conditioner is the major product of this type of composting. This approach to composting involves four basic steps: shredding, separation, composting and storage. Since only organic materials can be composted, the organics and inorganics must be separated. The first step typically involves the shredding of the incoming waste followed by air classification. Shredding improves the separability of the waste. In addition, the shredded waste has a greater surface area, which increases its susceptability to microbe attack.

The technology for actual composting is classified by approach: windrow and mechanical. In the windrow system, wastes are stacked in elongated piles. These piles must be of a certain minimum height or sufficient heat will not be generated. Furthermore, the piles can not be too high or the waste becomes compressed and anaerobic decomposition begins. The windrow system requires frequent turning (every 2-3 days) to aerate the waste and to include the surface waste in the thermophilic destruction that takes place in the center of the pile. No windrow projects using municipal solid waste as a feedstock are in operation in the United States, (Personal communication. Daniel Calacicco, U.S. Department of Agriculture, Beltsville, Maryland. July 12, 1978). Several attempts at this type of composting have been tried, but have been unsuccessful.

Mechanical systems are designed for frequent turning and aeration by air suction. A mechanical system is in operation in Altoona, Pennsylvania and one is under construction in Key West, Florida, (Personal communication. James Conlson, Fairfield Engineering Company, Marion, Ohio. June 22, 1978; and Roger Swift, City of Key West, Key West, Florida. July 12, 1978).

The final step is the storage of compost. In large scale use, such as agricultural applications, compost is placed on fields only prior to or after the planting season. Since compost is produced all year, it must be stored for use when needed. Some compost can be consumed by small-scale users (e.g., gardners) most of the year. Even these users have little use for compost during the winter season.

The economic outlook for composting is poor. The problem is the lack of a market for compost. Compost is classified as a soild conditioner because its NPK (nitrogen, phosphorous, potassium) content is too low for compost to legally be termed a fertilizer. Generally, those in agriculture view the value of compost as being negligible when viewed in comparison with the cost of application. The inorganic materials, particularly ferrous, separated from the organics prior to composting might be salable depending on plant location. This income should help to lower the cost of operation. Finally, a tipping fee will defray a portion of the costs.

The net system cost of a mechanical digester aerobic compost plant with ferrous recovery is about $28 per ton. The annual capital and operating costs per ton are $18 and $10 repectively. Although the markets for compost are poor, it was assumed that compost has a value as a top soil substitute. The value of top soil is $5 per ton. The value of compost and recovered ferrous would be just over $3 and $1 per ton of input refuse. The economics of aerobic composting at 100 TPD are detailed in Table 10.

Anaerobic Composting (Methane Digestion)--

The five basic steps for processing waste in a methane digester are: shredding, separation, digestion, gas treatment, and effluent treatment. The first step in processing municipal solid waste is to shred the incoming waste. The shredding operation achieves two objectives: (1) allows for a more efficient separation of the organic and inorganic, noncompostable material, and (2) reduces the waste to a smaller homogeneous size and increases surface area, which improves the susceptability of waste to decompostion. An air classifier would be used to separate the generally lighter organic materials from the heavier inorganic fraction of the waste stream. As the waste enters the digester it is mixed with nutrients (e.g., sewage sludge) into a slurry. Once in the digester, the contents should be stirred frequently to allow uniform digestion of the materials. Temperature must also be maintained at a constant level. This can be done without applying heat to the reaction in warmer climates (11). However, as mentioned previously, an outside heat source must be used in colder climates.

The gaseous products of anaerobic digestion are methane, carbon dioxide, and a small quantity of hydrogen sulfide. The latter gas must be removed before methane can be transported in a pipeline. This can be done via several processes.

The remaining effluent can be recovered by separating the liquids from the solids. This material which has a volume of only 25 percent of the incoming waste can be used as a soil conditioner. With a heating value of 4,000 BTU per pound, this material could be burned to generate steam (12).

The economics of an anaerobic digester were unavailable. No commercial scale plant using solid wastes has been or is in operation. In mid-1978, a 100 ton per day demonstration plant began operation in Pompano Beach, Florida. This plant is operated by Waste Management, Inc. and was funded through a grant from the U.S. Department of Energy. It is projected that the methane will have a market value of around $2 per million BTU, (Personal communication. Peter Ware, Waste Management, Inc., Oak Brook, Illinois. July 12, 1978). This revenue prior to digestion has been estimated to be sufficient for the system to be profitable. The crucial question is the cost structure which will result in the plant operating at optimum economic output. The cost/operating parameters which will be examined to determine this point include temperature, residence time, ingredient mixtures, and power requirements.

Froth Flotation Units

Froth flotation is a standard mineral processing technique, which has been adopted for glass recovery. Separation takes place when an air bubble becomes attached to a particle having hydrophobic surface characteristics. These particles float, while those particles with non-hydrophobic surface characteristics tend to sink. The hydrophobic characteristic is achieved by treating the input material with a reagent prior to entering the flotation system (13).

The system input is a pretreated material such as the Black Clawson glass-rich fraction or the underflow from shredded air classified municipal refuse. The froth flotation developed by Occidential Research (formerly Garrett Research and Development) is as follows (14).

1. screen off + ½ inch material
2. coarse mill
3. float off paper and wood in water
4. remove + 8 mesh fraction (mostly metals)
5. fine mill to minus 32 mesh; remove minus 200 mesh
6. repulp, add proprietary chemical agents which form a froth to which the glass particles adhere
7. skim off the froth, clean and repeat froth floatation
8. clean the product magnetically and dewater

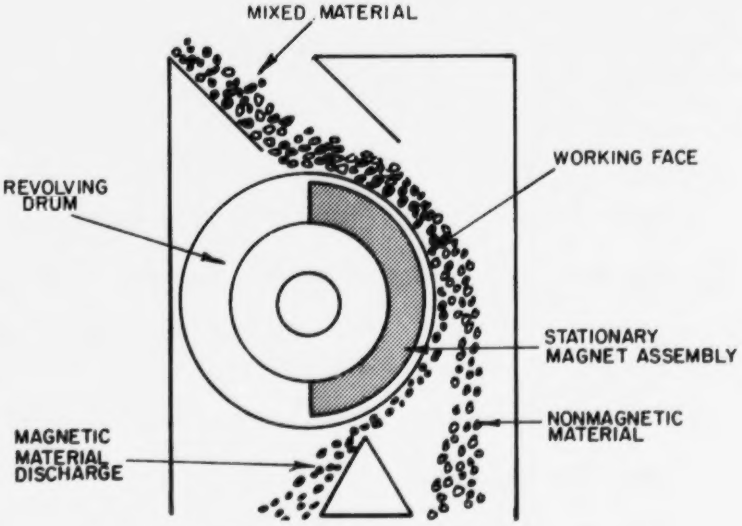
The product, according to Garrett is, 99.9 percent pure, and the froth flotation results in a loss of less than 5 percent of the glass contained in the original raw refuse.

The capital cost of a froth flotation unit in conjunction with a 2,000 ton day resource recovery system has been estimated to be $452,000. Based on a 24-hour day, 350 days per year operation, 4.5 tons of glass would be recovered per hour. Operating cost, including amortization, would be $5.54 per ton. By giving a credit of $1.50 per input ton for reduced disposal costs, estimated net cost would be $4.04 per ton of glass The revenue is difficult to estimate. The market for color mixed glass is very limited. The size of the glass particles is such that sortingis impossible at this time. Recovery plants with froth flotation units currently in shakedown are: New Orleans, Louisana, Baltimore County, Maryland, Hempstead, New York, and Milwaukee, Wisconsin. Two other plants are being constructed which will contain flotation units - Bridgeport, Connecticut and Monroe County, New York, (Personal communication. Joseph Duckett, National Center for Resource Recovery, Inc., Washington, D.C. July 25, 1978).

Magnetic Separators

Magnetic separators are used in conjunction with other refuse handling equipment to remove magnetic materials (mostly tin-coated steel cans) from mixed solid waste. In most applications the waste stream is scanned by a permanent magnet or an electromagnet. Ferrous material is removed and then stored separately for recycling.

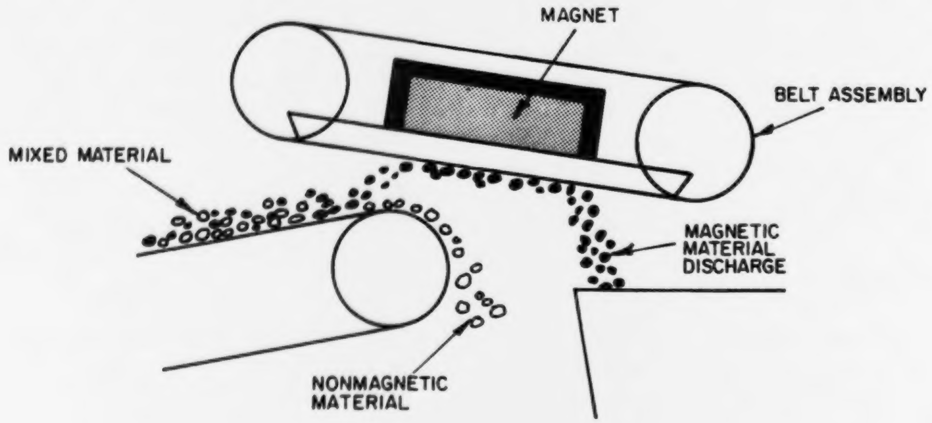
Two magnetic separation systems have developed and are available in the U.S. at this time; drum separators and overhead belt magnets (16). In the figure below a typical drum separator setup is shown. The magnet may be either permanent or an electromagnet.



MAGNETIC DRUM SEPARATOR

As the outside revolving drum rotates nonmagnetic material drops off, leaving the ferrous fraction adhering past the angle of repose to the drum. When the drum rotates past the magnets influence the adhering material drops off into a separate discharge. In some installations secondary drum separators have been installed (two in series) because of contamination problems (non-ferrous material mixed with the separated ferrous fraction).

The overhead belt separator is similar to the drum system except that the drum is replaced by a conveyor belt and the unit is suspended above the waste stream. The figure below depicts a typical installation.


MAGNET
BELT ASSEMBLY
MIXED MATERIAL
MAGNETIC MATERIAL DISCHARGE
NONMAGNETIC MATERIAL

MAGNETIC BELT SEPARATOR

As with the drum unit, either an electro or permanent magnet can be used. The conveyor may be mounted perpendicular or parallel to the waste stream, although experience has shown that a parallel configuration with the separation conveyor traveling faster than the waste conveyor produces a less contaminated separation. Contamination of the recovered metals, usually with paper and plastic, is the primary problem with magnetic separators. This problem can be alleviated by arranging drum separators in series, or installing belt separators with several magnets of alternating polarities. Units of this type agitate the ferrous material as it moves from one magnetic field to another, allowing contaminated material to fall away. A bend in the conveyor is usually added as well to enhance this effect.

Fine tuning of the separator also can lead to improved product composition, field strength, belt and drum speed, discharge positioning and belt spacing. These variables can affect contamination. Several methods are available for cleaning the recovered product including air knives (see section on air classifiers) and incineration.

In most recovery operations, the solid waste is usually shredded prior to magnetic classification. Shredding produces a homogeneous waste stream and a cleaner product. Air classification typically follows shredding in resource recovery facilities. This process removes the lighter, organic fraction leaving the heavier metal and glass components of the waste stream. This combination has been reported to produce a product containing less than 2% of non-ferrous material. This is an acceptable level of contamination for most markets. Trommel screens also have been advanced as an acceptable pretreatment for magnetic separation. Experiments indicate that several screenings would be necessary to provide the same purity as air classification.

Ferrous recovery from incinerator ash is another application utilizing magnetic separators. Contamination of the recovered metals is less of a problem, but there is virtually no market for incinerated scrap, (Personal communication. Howard Ness, National Association of Recycling Industries, New York, New York. July 20, 1978).

The material separated from a typical residential raw waste stream will contain over 50% tin-plated cans. Including bimetalic tin-plated cans and bimetallic non-tin cans accounts for over 75% of the ferrous fraction. Other sources report between 50-60% for the tin-steel can fraction, (Personal communication. Ronald Kinsey, Resource Technology Corporation, San Jose, California. July 7, 1978).

The average selling price for reclaimed iron and steel scrap in the United States in mid-year 1978 was approximately \$40 per ton (17). At this price, a gross revenue of \$2.88 per input ton would be realized at 8% magnetic metals in the incoming waste and 90% recovery efficiency. Of course, gross revenue will vary depending on the percent of ferrous in the waste stream and the amount of pre-processing, which relates to recovery efficiency. Capital costs for shredding and magnetic separation equipment make applicability to small waste streams marginal or unattractive (13). Magnetic separation and scrap recovery can be attractive where handling and processing (e.g., shredding) equipment is already installed. The capital cost of a 100 TPD magnetic separator is $40,000. The cost of operation, including amortaization, is less than $1 per input ton.

Magnetic separation and ferrous recovery becomes more attractive as the ferrous fraction of the waste increases. At some specialized facilities it may exceed 15%, in which case substantial revenue and disposal costs savings could be realized from recovery.

Magnetic separation is a technically proven method of recovering the ferrous fraction of a mixed waste stream. Full scale recovery facilities use magnetic separation as a standard part of the separation process. In addition, magnetic separation commonly is practiced at facilities which shred refuse prior to landfill. Two such facilities are located in Outagamie County, Wisconsin and Omaha, Nebraska.

Modular Incinerators

Incineration of solid waste is an old technology which has lately received renewed attention. Improved designs, which have greatly reduced costs for meeting air pollution standards, coupled with increased interest in recovering the energy value of solid waste, have resulted in a rebirth of the incinerator industry. The advent of controlled air incinerators has resulted in units which reportedly can meet air pollutant emission codes in most localities. A controlled air incinerator has two combustion chambers in which the air-to-fuel ratio in each is closely regulated. In the primary chamber the refuse fuel is ignited and burned in a lean (less than stoichiometric air-to-fuel ratio) environment. Unburned organics along with the exhaust pass under low turbulent flow conditions to a secondary chamber (somtimes call an after-burner), where combustion in an excess air environment takes place,(Figure 16). Typical temperatures in the primary combustion chamber are 1300-1600°F. Depending on the nature of the waste, auxillary fuel (usually fuel oil or gas) may be used in the secondary chamber to promote complete combustion.

The claimed advantage of controlled air incinerators over the standard design is their marketability to meet air pollution control regulations. Particulate emissions from a controlled air incinerator are usually well within the limits.

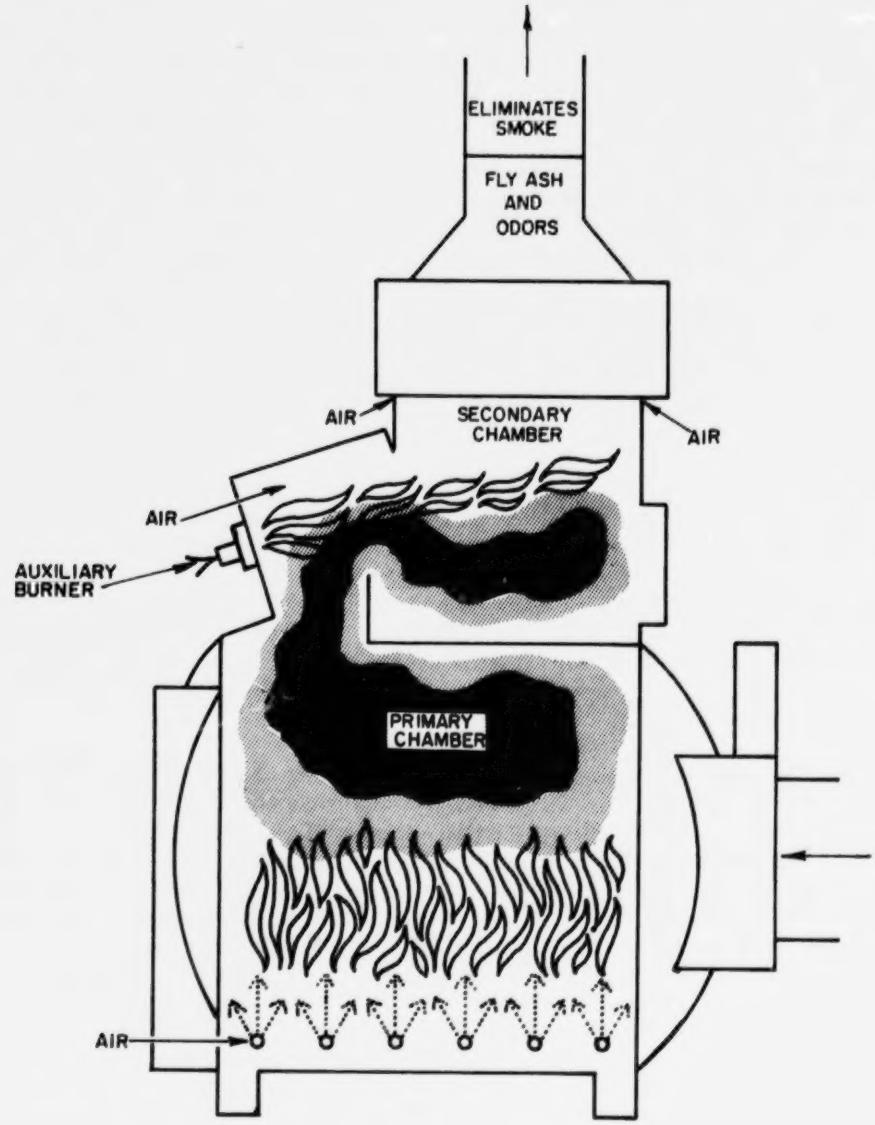

ELIMINATES SMOKE
FLY ASH AND ODORS
AIR
SECONDARY CHAMBER
AIR
AIR
AUXILIARY BURNER
PRIMARY CHAMBER
AIR

Figure 16. Typical controlled air incinerator

Because combustion of organics is fairly complete, and entrainment of inorganics, through low turbulence in the primary chamber, is minimized, conversely a traditional, uncontrolled one combustion chamber incinerator usually requires an expensive wet scrubber or electrostatic precipitator to meet air pollution codes.

The prospect of recovering the energy content in refuse has encouraged many manufacturers to incorporate some form of heat utilization into their incinerator equipment. Despite the increased capital costs involved, the current price of traditional energy has increased to the point where refuse generated steam of electricity is quite competitive.

Refuse fueled package boiler/incinerators are similar to fossil fueled units except for waste heat dumping capability, Figure 17. Whereas a fossil fuel boiler can be shut down when energy is not needed, the flow of refuse to be incinerated in a solid waste fueled boiler is independent of energy utilization demand and must be burned whether the resultant heat is wanted or not. Most systems; therefore, incorporate some provision for dumping useless hot air or steam.

A cursory pre-sort must be conducted before raw solid wsate can be fed into an incinerator. Gross incombustibles must be removed to prevent mechnical damage, jamming, and quenching of the combustion chamber. Some units (particularly those with moving grates) require the incoming feed to be shredded to approximately four inches.

Ash removal can be automatic or manual. Materials recovery (particularly ferrous) can be practiced by further processing the ash. Once cooled the residue is stored in a covered hopper until it can be transported to the disposal site. Volume reductions of 15-1 are typical. For most waste generators alternate disposal costs are significantly reduced from pre-incineration levels.

Recovering the energy content from solid waste has advantages for small waste generators. Many waste generators, particularly prisons, hospitals and universities, have a need for steam and hot water. In most cases these energy demands are supplied by combustion of fossil fuels on site. By replacing these purchased fuels with solid waste, cost savings might be possible.

As is the case with all resource recovery operations, the economic evaluation depends heavily on the availability of a customer for the recovered resource. In the case of waste heat recovery this is particularly true since hot air or steam can be transported only short distances and cannot be stored. The ideal situation is one where the refuse generator can utilize the resultant energy.

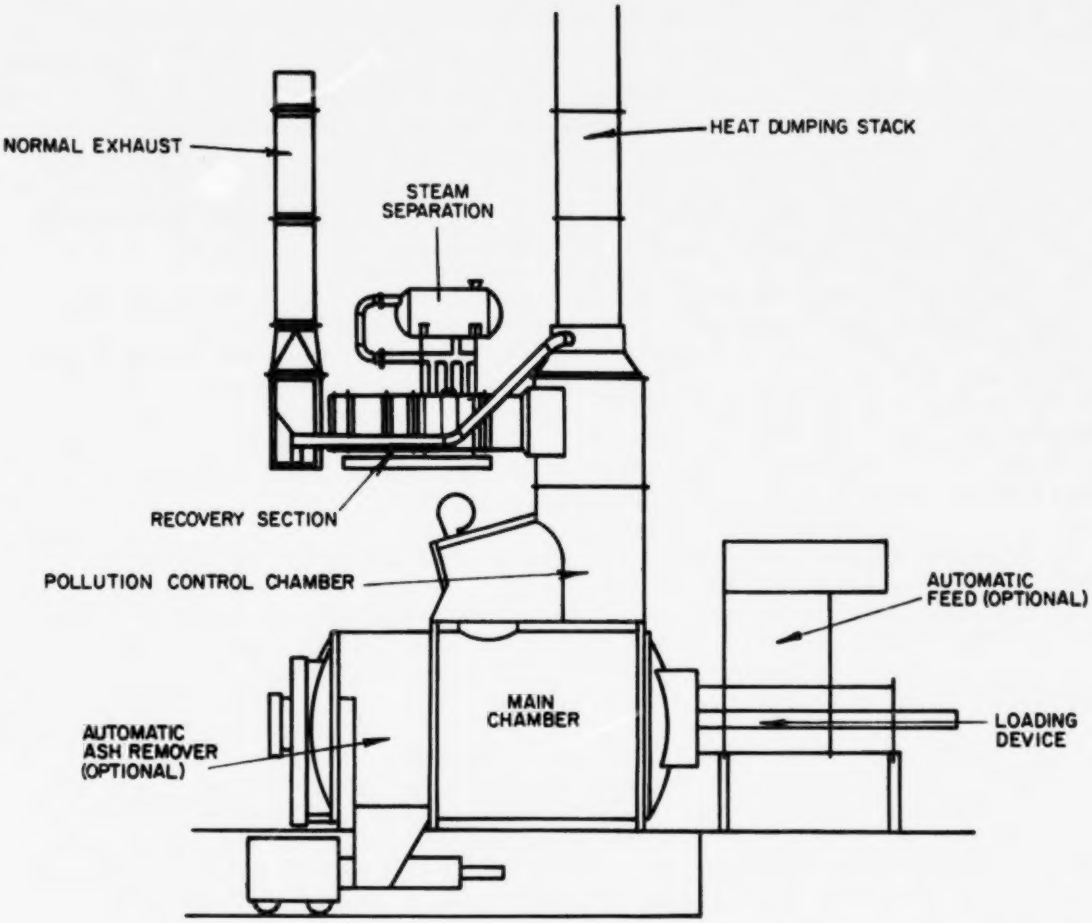

NORMAL EXHAUST
HEAT DUMPING STACK
STEAM SEPARATION
RECOVERY SECTION
POLLUTION CONTROL CHAMBER
AUTOMATIC FEED (OPTIONAL)
MAIN CHAMBER
AUTOMATIC ASH REMOVER (OPTIONAL)
LOADING DEVICE

Figure 17. Solid waste incinerator with heat recovery

If this is not the case or if the energy consumer has an energy demand which is intermittant, the conversion of waste heat to electrical power can overcome some of the above-mentioned problems but increases both capital and operating costs.

Although heat recovery from large (1000 TPD) municipal incinerators has been practiced at numerous locations, heat recovery from smaller package incinerators is fairly recent, dating from 1972. The cost savings in utilization of factory assembled package incineration units is on the same scale as fossil fuel boilers.

The capital and operationg costs of a 100 TPD modular incinerator with energy recovery will vary depending upon the final form of the energy used. The costs for the production of steam at 100 TPD modular incinerator are outlined in Table 12.

Hot air, steam and electricity are the alternative forms listed from least to most expensive. Steam production requires a boiler. Electricity production requires, in addition to a boiler, a turbine generator, a condenser and a switch gear.

In the past five years the number of small scale modular incinerators utilizing waste heat recovery has increased significantly. Units are located in over a dozen states. A typical installation is located at the Pentagon building near Washington, D.C. This facility has been in service sightly under two years. It is sized to handle 25 TPD of solid waste, and the energy produced is consumed internally. Similar units are located in Blytheville, Siloam Springs and North Little Rock, Arkansas and Groveton, New Hampshire (18).

Pyrolytic Units

Through pyrolysis a synthetic fuel oil, which contains approximately eight bbl of pyrolysis oil/bbl of #2 fuel oil, can be obtained. A number of commercial processes have been developed which pyrolyize the organics to varying combinations of oil and gas. In all of them the shredded waste is charged to a reactor where the material is subjected to a high temperature, low oxygen environment. Volatile components are driven off, then condensed, to recover the liquids while the gas produced is either recovered or recycled. The solid residue left behind is called char and has a number of potential uses such as fuel or filter media.

The liquid component of the pyrolysis process is the principle product. It can be used to replace fuel oil directly in most combustion units. Yields vary from 40-80 gallons of oil per ton of refuse depending upon initial refuse composition and the pyrolysis process. Utilization of pyrolyssis oil has generally taken place in large utility boilers. Typically the synthetic oil is blended with regular fuel such as #6 fuel oil.

The pyrolysis process consumes a certain amount of energy and a certain amount of energy is lost from the feed during transition. Whereas a ton of refuse can deliver approximately 14.6×10^6 BTU as (d-Rdf, densified-refuse-derived-fuel), when converted to oil only 4.8×10^6 BTU are available. When pyrolysis oil is used to replace other fossil fuels, 8 bbl of natural oil/bbl of pyrolysis oil, or 4500 ft^3 of natural gas/bbl of pyrolysis oil or .25 ton of coal/bbl of pyrolysis oil are saved. The same volume of waste material as in RDF is removed from the disposal process in pyrolysis, assuming the char is utilized. This may not be a valid assumption; however, because the char has a low unit value and is difficult to store and ship. If (as may be the case in most operations) the char is disposed along with the other residue the savings in hauling costs are not nearly as significant. As much as .75 of the original waste volume could be sent to disposal if the char is not utilized.

The solid waste pyrolysis systems which have been built to date have not shown this type system to be practical on a small scale due to economic factors. The two large scale systems, which have been constructed (Baltimore, Maryland - 1000 TPD and San Diego, California - 200 TPD), have not proven to be successful technically at this time (18).

Pyrolysis of solid waste to form liquid fuel is a new technology which has not been extensively applied on a large scale. It appears, at this stage of development, that pyrolysis is a very capital intensive system more applicable to large scale systems. The process is not as efficient, based on energy balances, as RDF production, but the final product, fuel oil, does possess superior qualities to RDF.

Shredders

Shredding of solid waste is a necessary prelude for several forms of handling and disposal. Many incinerator designs, particularly those with moving grates, require shredding of the waste feed, usually to 4 inches. Some landfill operations utilize shredding for refuse pretreatment in order to facilitate compaction and reduce vector infestation. Most resource recovery activities begin with shredding, followed by air or/and magnetic separation. Several of the novel technologies such as pyrolysis and composting also are dependent upon shredding as a first step.

The preparation of refuse derived fuel (RDF) requires at least one shredding step and in some systems a secondary shredding step is added. Shredding improves the handling characteristics of refuse by providing a uniform particle size. Magnetic and air separation operations are usually designed to sort uniformly shredded waste. The use of shredding to process solid waste has grown considerably during the 1970's. One recent survey found that shredding operations in the U.S. and Canada have increased from 27 in 1971 to 80 in 1976 (19). Many of these facilities are located adjacent to landfills where shredding has become popular due to reduced cover and volume requirements, and current Federal regulations.

Shredding of raw waste and handling of shredded waste pose serious safety problems which have led some companies to design refuse systems specifically excluding shredding. Explosions are one serious problem which occur. In one study by Nollet and Sherwin 30 explosions were recorded over a 5 year (800,000 + tons) period (19). Fire hazard is another problem. For instance the Ames, Iowa shredding facility experienced 5 fires in the first year of operation, and the Brevard County, Florida shred/landfill operation suffered a serious fire which lasted 2 weeks.

Two types of solid waste shredders are currently available in the U.S. The most common operates on the hammer principal, Figure 18. In these machines a series of disc mounted hammers are rotated at high speed in a durable housing. Solid waste is fed into the path of the hammers and is broken apart by impaction. Provision is usually made for non-destructable material to be ejected.

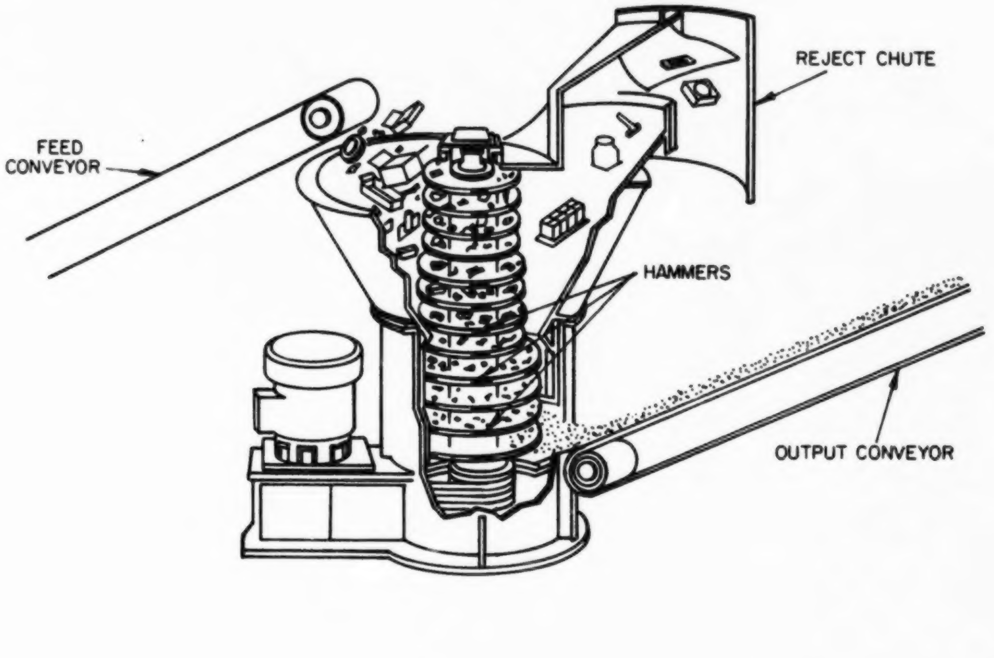


Figure 18. Vertical Hammer Shredder

The radius of the hammers increases and the radius of the outer casing decreases as the material moves down through the unit, resulting in increasingly smaller shredding. This design parameter is used to control final particle size.

Horizontal shredders utilizing the hammer principal are also available. Refuse usually is fed in the top of the unit and the momentum transfer from the hammers to the waste propels it through the units.

Another shredding method in widespread use has counter current revolving cutting edges to tear and slice material into small pieces. These machines are referred to as shear shredders, Figure 19.

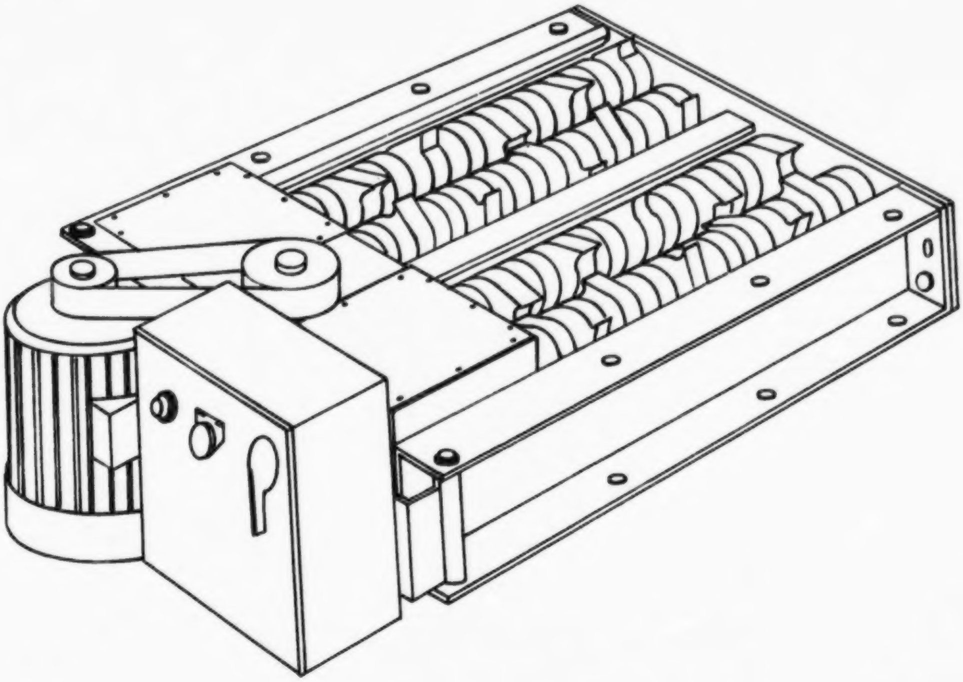


Figure 19. Shear Shredder

Although shear shredders cannot handle as wide a range of materials as hammer shredders, they do offer advantages such as quieter operation, less safety hazard, and energy savings. Besides shredders designed for general refuse, some units, both shear and hammer type units, have been designed for specific feed material. Tires, pallets, plastic, or glass bottles, documents, automobiles, cans and metal turnings can all be shredded by machines specifically designed for those applications. A typical 100 TPD shredder cost $350,000. The cost of operation including amortization is about $6.75 per input ton.

Trommel Screens

Trommeling is the least complex and least expensive operation commonly performed in solid waste processing. A rotary trommel screen is a perforated cylindrical chamber, usually mounted at a slight downward slope, which slowly rotates as the solid waste passes through it. Smaller particles fall through the perforations dependent on the hole size, Figure 20. Capacity can be adjusted by varying the angle of repose or rotation speed.

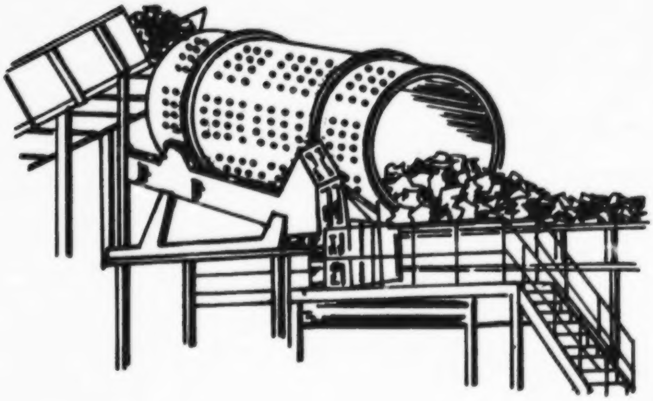


Figure 20. Rotary trommel screen.

Trommel screens have a number of applications in solid waste processing. They can be used at the front end to screen incoming raw refuse. In some cases, shredder load can be substantially decreased (50% is claimed) in this manner. Additionally, abrasive materials such as glass and ceramics are removed reducing shredder maintenance. The principal application of screening, however, is in processing the light fraction of air separated, shredded solid waste. In preparing salable products it is desirable to separate these components. A rotary trommel screen will pass most paper and plastic, while dropping glass cullet and other small contaminants.

Rotary trommel screens represent perhaps the lowest capital cost of major system component. Prices, in the 100 TPD and less range are below $10,000. Operating costs, including maintenance, for the 4-7 hp motor rotating the drum are insignificant.

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APPENDIX F

ENERGY ANALYSIS OF ALTERNATIVE RESOURCE RECOVERY SYSTEMS

The purpose of this analysis is to compare the direct energy expended and/or conserved for disposal, source separation, and modular incineration with energy recovery. The analysis indicates that all the resource recovery options consume less energy than landfill disposal, Table 28. The approach used was developed by Resource Planning Associates.

Only direct energy consumption or conservation was considered in the analysis. Direct energy includes the energies required to operate trucks and machinery. In other words, the energies needed to power the designated solid waste systems. Indirect energy was not considered. This type of energy is defined as the energies used to construct and maintain the equipment needed for the systems to operate.

The discards in the various waste generators could be managed in numerous ways. Each variation will affect the energy balance of the alternative systems. For example, the distance to market for a recovered material might be 20 miles in one case and 100 miles in another. The longer distance will require more energy than the shorter distance. Thus, a longer distance to market willlower the quantity of energy conserved by recovery, and reduce the net energy savings attributable to the system. To analyze the energy expenditures and saving, the solid waste systems were divided into four subsystems and representative, hypothetical situations were established. The subsystems are:

- Collection: collecting and hauling discards to a preparation or treatment site
- Preparation: sorting, crushing, shredding, baling, compacting or otherwise processing material for recovery
- Transportation: hauling recyclables to a treatment site
- Treatment: use of recovered materials in manufacturing process, incineration to recover energy, or landfilling

TABLE 28. ENERGY EXPENDITURE AND CONSERVATION FOR SELECTED SOLID WASTE SYSTEMS.

	Landfill Only	Residential Source Separation-Newsprint-and Landfill	Residential Source Separation-Glass, Ferrous and Aluminum-and Landfill	Residential Source Separation-Newsprint, Glass, Ferrous and Aluminum-and Landfill
Collection	139	138	136	136
Preparation	--	15	4	19
Transportation	--	14	36	50
Treatment	59	(109)	(991)	(1,159)
Total	198	58	(815)	(954)

	Non-Residential Source Separation-High-Grade Paper-and Landfill	Non-Residential Source Separation-Corrugated-and Landfill	Modular Incineration with Energy Recovery and Landfill
Collection	46	43	104
Preparation	141	152	28
Transportation	135	143	--
Treatment	(3,501)	(2,657)	(7,568)
Total	(3,259)	(2,319)	(7,436)

*Parenthesis indicates energy conservation

The conditions in the hypothetical situations are:

- Landfill
  - Collection
    - Residential solid waste
      - 20 cubic yard packer truck
      - Collection and haul distance: 20 miles round trip
    - Non-residential solid waste
      - 30 cubic yard front-loading packer truck
      - Collection and haul distance: 15 miles round trip
  - Treatment: spreading and covering refuse with a bulldozer
- Source Separation
  - Collection
    - Residential solid waste
      - 20 cubic yard collection truck
      - Collection and haul distance: 15 miles round trip
    - Non-residential solid waste
      - High-grade paper: 4 ton covered bed truck
      - Corrugated: heavy duty truck
      - Collection and haul distance: 10 miles round trip
    - Preparation
      - Paper: shredding and baling
      - Glass, ferrous and aluminum: hammermill, vibrating screen, and magnetic separation
    - Transportation
      - Haul distance: 100 miles round trip

    - Treatment (recovered material - manufactured product)
        - Newsprint - newsprint
        - High-grade - tissue
        - Corrugated - corrugated
        - Glass - glass
        - Ferrous - steel
        - Aluminum - aluminum

- Modular Incineration with Energy Recovery
    - Collection
        - 20 cubic yard packer truck
        - Collection and haul distance: 15 miles round trip
    - Preparation
        - Waste handling by small front-end loader
    - Treatment
        - Incineration and recovery of the energy
        - Landfilling of residue

The remainder of the appendix is composed of two sections. The first section, Comparative Analysis, examines the seven waste management alternatives selected. In this section, the data generated in the second section, Data Calculations, are brought together to determine the net energy balance for the alternatives. To check the data in the first section, refer to the second section.

COMPARATIVE ANALYSIS

The solid waste management systems considered are:

1. Landfill only
2. Residential source separation: newsprint and landfill
3. Residential source separation: glass, ferrous and aluminum and landfill

4. Residential source separation: newsprint, glass, ferrous and aluminum and landfill
5. Non-residential source separation: high-grade paper and landfill
6. Non-residential source separation: corrugated and landfill
7. Modular incineration with energy recovery

Landfill Only

Energy consumption occurs during collection (139×10^3 BTU per ton) and treatment (landfill: 59×10^3 BTU per ton). Total energy use is 198×10^3 BTU per ton.

Residential Source Separation and Landfill

The recovery rate is assumed to be 30 percent (1). The presence of the recyclables in the waste stream are (2):

Newsprint:	9 percent
Glass:	13 percent
Ferrous:	9 percent
Aluminum:	1 percent

Residential source separation-newsprint-and landfill--

The percent of the waste stream recovered and the percent requiring landfill is:

Recovered:	2.7 percent
Landfill:	97.3 percent

The calculations to adjust the energy value for newsprint source separation and landfill were accomplished in the following manner:

- Landfill
  - Collection : $(139 \times 10^3 \text{ BTU}) \times (.973) = 135 \times 10^3$ BTU
  - Treatment : $(59 \times 10^3 \text{ BTU}) \times (.973) = 57 \times 10^3$ BTU
- Newsprint
  - Collection : $(104 \times 10^3 \text{ BTU}) \times (.027) = 3 \times 10^3$ BTU
  - Preparation : $(543 \times 10^3 \text{ BTU}) \times (.027) = 15 \times 10^3$ BTU

- Transportation: $(518 \times 10^3$ BTU$) \times (.027) = 14 \times 10^3$ BTU
- Treatment : $(6140 \times 10^3$ BTU$) \times (.027) = 166 \times 10^3$ BTU

The energy consumed or conserved per ton in each subsection is:

Collection : $(135 \times 10^3$ BTU$) + (3 \times 10^3$ BTU$) =$
138×10^3 BTU (consumed)

Preparation : $(15 \times 10^3$ BTU (consumed)

Transportation: $(14 \times 10^3$ BTU (consumed)

Treatment : $(166 \times 10^3$BTU$) - (57 \times 10^3$BTU$) = 109 \times 10^3$BTU(conserved)

The net energy balance per ton is:

$(109 \times 10^3$BTU$) - [(138 \times 10^3$BTU$) + (15 \times 10^3$BTU$) + (14 \times 10^3$BTU$)] = 58 \times 10^3$BTU

Residential source separation glass, ferrous, and aluminum - and landfill--

The percent of the waste recovered by material category and the percent requiring landfill are:

- Glass : 3.9 percent
- Ferrous : 2.7 percent
- Aluminum: 0.3 percent
- Landfill: 93.1 percent

The calculation to adjust the energy value for glass, ferrous and aluminum recovery and residual disposal may be done in the following manner:

- Landfill
    - Collection : $(139 \times 10^3$ BTU$) \times (.931) = 129 \times 10^3$ BTU
    - Treatment : $(50 \times 10^3$ BTU$) \times (.931) = 55 \times 10^3$ BTU
- Glass, Ferrous and Aluminum
    - Collection : $(104 \times 10^3$ BTU$) \times (.069) = 7 \times 10^3$ BTU
    - Preparation : $(58 \times 10^3$ BTU$) \times (.069) = 4 \times 10^3$ BTU
    - Transportation: $(518 \times 10^3$ BTU$) \times (.069) = 36 \times 10^3$ BTU

- Treatment
    - -- Glass : (7,940 x 10^3 BTU)x(.039)=310 x 10^3 BTU
    - -- Ferrous : (16,430 x 10^3 BTU)x(.027)=444 x 10^3 BTU
    - -- Aluminum: (97,346 x 10^3 BTU)x(.003)=292 x 10^3 BTU

The energy consumed or conserved per ton in each subsection is:

Collection : (129 x 10^3 BTU)+(7 x 10^3 BTU) =
136 x 10^3 BTU (consumed)

Preparation : 4 x 10^3 BTU (consumed)

Transportation: 36 x 10^3 BTU (consumed)

Treatment :[(310 x 10^3 BTU)+(444 x 10^3 BTU)+
(292 x 10^3 BTU)] - (55 x 10^3 BTU)=
991 x 10^3 BTU (conserved)

The net energy conserved per ton is:
(991 x 10^3BTU)-[(136 x 10^3BTU)+(4 x 10^3BTU)+(36 x 10^3BTU)] =
815 x 10^3 BTU

Residential source separation - newsprint, glass, ferrous, and aluminum and landfill--

The percent of the waste stream salvaged and the percent requiring disposal are:

- Recovered: 9.6 percent
- Landfill: 90.4 percent

The calculation to adjust the energy values for landfill may be done as follows:

- Landfill
    - Collection : (139 x 10^3 BTU)x(.904)=126 x 10^3 BTU
    - Treatment : (59 x 10^3 BTU)x(.904)= 53 x 10^3 BTU

The adjusted energy values are taken from the two previous headings:

- Newsprint, Glass, Ferrous, and Aluminum:
    - Collection : (3 x 10^3 BTU)+(7 x 10^3 BTU) =
10 x 10^3 BTU

- Preparation : (15 x 10^3 BTU)+(4 x 10^3 BTU) = 19 x 10^3 BTU
- Transportation: (14 x 10^3 BTU)+(36 x 10^3 BTU) = 50 x 10^3 BTU
- Treatment : (166 x 10^3 BTU)+(310 x 10^3 BTU) + (444 x 10^3 BTU)+(292 x 10^3 BTU) = 1212 x 10^3 BTU

The energy consumed or conserved per ton in each subsection is:

Collection : (126 x 10^3 BTU)+(10 x 10^3 BTU) = 136 x 10^3 BTU (consumed)

Preparation : 19 x 10^3 BTU (consumed)

Transportation: 50 x 10^3 BTU (consumed)

Treatment : (1212 x 10^3 BTU)-(53 x 10^3 BTU) = 1159 x 10^3 BTU (conserved)

Net energy conserved per ton of refuse is:

(1159 x 10^3 BTU)-[(136 x 10^3 BTU)+(19 x 10^3 BTU)+(50 x 10^3 BTU)]= 954 x 10^3 BTU

Non-Residential Source Separation - High-Grade Paper-and Landfill

The basic assumptions are (3):

- Percent of waste stream : 43 percent
- Recovery rate : 60 percent
- Percent of waste stream recovered: 26 percent
- Percent of waste for landfill : 74 percent

The calculation to adjust the energy values for high-grade paper recovery and landfill may be done as follows:

- Landfill
    - Collection : (46 x 10^3 BTU)x(.74) = 34 x 10^3 BTU
    - Treatment : (59 x 10^3 BTU)x(.74) = 44 x 10^3 BTU

- High-Grade Paper
  - Collection : (45 x 10^3 BTU)x(.26)= 12 x 10^3 BTU
  - Preparation : (543 x 10^3 BTU)x(.26)= 141 x 10^3 BTU
  - Transportation: (518 x 10^3 BTU)x(.26)= 135 x 10^3 BTU
  - Treatment : (14000 x 10^3 BTU)x(.26)= 3640 x 10^3 BTU

The energy consumed or conserved per ton in each subsection is:

Collection : (34 x 10^3 BTU)+(12 x 10^3 BTU) = 46 x 10^3 BTU (consumed)

Preparation : 141 x 10^3 BTU (consumed)

Transportation : 135 x 10^3 BTU (consumed)

Treatment : (3640 x 10^3 BTU)-(59 x 10^3 BTU) = 3581 x 10^3 BTU (conserved)

The net energy conserved per ton is:

(3581 x10^3 BTU)-[(46 x 10^3 BTU)+(141 x 10^3 BTU)+(135 x 10^3 BTU)]= 3259 x 10^3 BTU

Non-Residential Source Separation - Corrugated and Landfill

The basic assumptions are (4):

- Percent of waste stream : 40 percent
- Recovery rate : 70 percent
- Percent recovered : 28 percent
- Percent of waste for landfill: 72 percent

The calculation to adjust the energy values for corrugated recovery and landfill may be done as follows:

- Landfill
  - Collection : (46 x 10^3 BTU)x(.72)= 33 x 10^3 BTU
  - Treatment : (59 x 10^3 BTU)x(.72)= 42 x 10^3 BTU
- Corrugated
  - Collection : (36 x 10^3 BTU)x(.28)= 10 x 10^3 BTU

- Preparation : (543 x 10^3 BTU)x(.28)= 152 x 10^3 BTU
- Transportation: (518 x 10^3 BTU)x(.28)= 143 x 10^3 BTU
- Treatment : (9640 x 10^3 BTU)x(.28)= 2699 x 10^3 BTU

The energy consumed or conserved per ton in each subsection is:

Collection : (33 x 10^3 BTU)+(10 x 10^3 BTU) =
43 x 10^3 BTU (consumed)

Preparation : 152 x 10^3 BTU (consumed)

Transportation: 143 x 10^3 BTU (consumed)

Treatment : (2699 x 10^3 BTU)-(42 x 10^3 BTU) =
2657 x 10^3 BTU (conserved)

The net energy conserved per ton is:

(2657 x 10^3 BTU)-[(43 x 10^3 BTU)+(152 x 10^3 BTU)+(143 x 10^3 BTU)]=
2319 x 10^3 BTU

Modular Incineration with Energy Recovery

The basic assumptions are (5), (6):

- Percent combustibles: 80 percent
- Weight reduction : 75 percent

The energy consumed or conserved per ton in each subsection is:

Collection : 104 x 10^3 BTU (consumed)

Preparation : 28 x 10^3 BTU (consumed)

Transportation: 0

Treatment : 7568 x 10^3 BTU (conserved)

No energy is used to transport discards in this alternative. The collected wastes are delivered directly to the treatment site for preparation and treatment.

The net energy conserved per ton is:

(7568 x 10^3 BTU)-[(104 x 10^3 BTU)+(28 x 10^3 BTU)] =
7436 x 10^3 BTU

DATA CALCULATIONS

The basic data used in comparing the energy consumption and/or conservation of the selected solid waste alternatives are developed in this section. The calculations are divided into four categories: collection; preparation; transportation; and treatment. These terms were defined previously.

Collection

No energy savings will occur in any of the alternatives.

- Residential
  - Energy use is for the operation of diesel fuel collection trucks. The basic assumptions are, (Personal communication. Warren Gregory, Atlantic Equipment, Inc., Washington, D.C. June 20, 1978):
    - Capacity: 20 cubic yards (5 tons)
    - Mileage: 4 mpg
  - Thermal value of diesel fuel: 139×10^3 BTU per gallon

The route and haul distance to a landfill, including return, is assumed to be 20 miles. The energy use may be calculated as follows:

$[(20 \text{ miles}) \times (139 \times 10^3 \text{ BTU/gal})] \div [(4 \text{ miles/gal}) \times (5 \text{ tons})] = 139 \times 10^3 \text{ BTU/ton}$

For the source-separated materials, the route and haul distance to a preparation site, including return, is assumed to be 15 miles. A shorter haul distance than for landfill is used because preparation sites tend to be located within urban areas. The energy use may be calculated as follows:

$[(15 \text{ miles}) \times (139 \times 10^3 \text{ BTU/gal})] \div [(4 \text{ miles/gal}) \times (5 \text{ tons})] = 104 \times 10^3 \text{ BTU/ton}$

- Non-Residential
  - Energy use is for the operation of diesel and gasoline fuel collecting trucks. The basic assumptions are:
    - Diesel fuel trucks haul wastes to landfill, (Personal communication. Warren Gregory, Atlantic Equipment, Inc., Washington, D.C. June 20, 1978).

        - Capacity: 30 cubic yards (7.5 tons)
        - Mileage: 6 mpg (fewer stops per load than residential truck, thus higher mileage)
    - Gasoline fuel truck; hauls high-grade paper, (Personal communication. Warren Gregory, Atlantic Equipment, Inc., Washington, D.C. June 20, 1978)
        - Capacity: 4 tons
        - Mileage: 7 mpg
- Thermal value of gasoline: 125 x 10^3 BTU per gallon
    - Diesel fuel truck; hauls corrugated
        - Energy use: 3.45 x 10^3 BTU per ton per mile (7)

The haul distance to a landfill, including return, is assumed to be 15 miles. Energy use may be calculated as follows:

$[(15 \text{ miles})\times(139 \times 10^3 \text{ BTU/gal})]\div[(6 \text{ miles/gal}) \times (7.5 \text{ tons})] = 46 \times 10^3 \text{ BTU/ton}$

The haul distance is a preparation site for high-grade paper, including return, is assumed to be 10 miles. Energy use may be calculated as follows:

$[(10 \text{ miles})\times(125 \times 10^3 \text{ BTU/gal})]\div[(7 \text{ miles/gal})\times(4 \text{ tons})] = 45 \times 10^3 \text{ BTU/ton}$

For corrugated, the haul distance to a preparation site, including return, is assumed to be 10 miles. Energy use may be calculated as follows:

$(10 \text{ miles})\times(3.45 \times 10^3 \text{ BTU/ton-mile})=36 \times 10^3 \text{ BTU/ton}$

- Modular Incineration
    - Energy to collect refuse in this alternative is assumed to be the same as for residential source separation (104 x 10^3 BTU per ton) because of shorter haul distance to the incinerator than a landfill.

Preparation

Energy is expended in this subsection only for resource recovery. Paper products are baled. The jointly collected glass, ferrous and aluminum are separated. The refuse to be incinerated is transferred from the collection trucks to the incinerator.

- Paper

  - Paper is delivered to a paper stock dealer, where two small front-end loaders move the paper onto a conveyor for shredding and baling. The baled paper is loaded onto trucks by the front-end loaders. The assumptions on the front-end loader are, (Personal communication. R.H. Brichner, Allis-Chalmers Corporation, Appleton, Wisconsin. July 24, 1978):

    -- Energy use: 2.5 gallons per hour

    -- Capacity: 11 tons per hour

The energy use per ton may be calculated as follows:

$(2.5 \text{ gal/hr}) \times (125 \times 10^3 \text{ BTU/gal}) \div (11 \text{ tons/hr}) =$
$28 \times 10^3 \text{ BTU/ton}$

The energy assumptions for baling are (8):

-- Energy use: 50 kwh per ton

-- Energy: electricity (thermal value: 10.3×10^3 BTU/kwh)

Baling energy use per ton may be calculated as follows:

$(50 \text{ kwh/ton}) \times (10.3 \times 10^3 \text{ BTU/kwh}) = 515 \times 10^3 \text{ BTU/ton}$

Total energy use for paper preparation is:

$(28 \times 10^3 \text{ BTU/ton}) + (515 \times 10^3 \text{ BTU/ton}) = 543 \times 10^3 \text{ BTU/ton}$

- Glass, Ferrous, and Aluminum

  - The combined materials are delivered to a processing point for separation. Two small front-end loaders move the materials onto a conveyor. The recyclables are processed in a hammermill, vibrating screen, and magnetic screen for separation into material categories.

    The energy use of the front-end loaders is the same as calculated above: 28×10^3 BTU per ton. Electricty consumption to operate the mechanical separation system is: 2.9 kwh per ton (9).

Energy consumption per ton may be determined as follows:

$(2.9 \text{ kwh/ton})\text{x}(10.3 \text{ x } 10^3 \text{ BTU/kwh})=30 \text{ x } 10^3 \text{ BTU/ton}$

Total energy use for glass, ferrous and aluminum preparation is:

$(28 \text{ x } 10^3 \text{ BTU/ton})+(30 \text{ x } 10^3 \text{ BTU/ton})=58 \text{ x } 10^3 \text{ BTU/ton}$

Modular Incineration with Energy Recovery

Solid waste is delivered to the incinerator. The refuse is moved to the charging hoppers by small front-end loaders. The loaders used in this situation use the same energy as the other loaders described in this subsection. Energy use is:

$28 \text{ x } 10^3 \text{ BTU/ton}$

Transportation

All energy use in this subsection is for resource recovery. No energy savings occur.

The transportation assumptions are:

- Only source-separated materials are transported
- Vehicles: diesel-fuel heavy duty trucks
- Energy use: $3.45 \text{ x } 10^3$ BTU per ton-mile (10)
- Haul distance: 100 miles
- Return trip: trucks are empty; energy consumption is one-half that used in delivery.

Transportation energy may be calculated as follows:

$(4.35 \text{ x } 10^3 \text{ BTU per ton-mile})\text{x}(100 \text{ miles per trip})\text{x}(1.5 \text{ trips})=$
$517.5 \text{ x } 10^3 \text{ BTU/ton}$

Treatment

Energy is conserved in each recovery process in this subsection. Energy is consumed in the disposal option.

The energy data presented for virgin raw materials includes the diesel energy consumed in extraction or harvesting through product manufacture.

- Landfill
  - The assumptions on landfilling are (11):
    - Diesel-fuel bulldozer is used to spread and cover waste
    - Energy consumption: 59 x 10^3 BTU per ton
- Glass
  - Recovered glass is assumed to be used in new glass manufacture at a 50/50 mixture with virgin raw materials. The energy requirements for glass from 100 percent virgin raw materials and a 50/50 mixture are (12):
    - Virgin raw materials: 15,670 x 10^3 BTU per ton
    - 50/50 mixture: 11,700 x 10^3 BTU per ton

The energy savings per ton of glass are:

(15,670 x 10^3 BTU/ton)-(11,700 x 10^3 BTU/ton) =
3,970 x 10^3 BTU/ton

Since only a half ton of cullet is used per ton of glass in the 50/50 mixture, the energy savings per ton of glass must be doubled to determine the energy saving per ton of cullet. Therefore, the energy savings from recycled glass are: 7,940 x 10^3 BTU per ton.

- Ferrous
  - The recovered ferrous materials are assumed to be used as a substitute for pig iron. The energy consumed in the production of pig iron from virgin raw materials and the processing of scrap for pig iron substitution is (13):
    - Pig iron production: 16,780 x 10^3 BTU per ton
    - Processing of scrap: 350 x 10^3 BTU per ton

The energy savings per ton of secondary ferrous are:

(16,780 x 10^3 BTU/ton)-(350 x 10^3 BTU/ton) =
16,430 x 10^3 BTU/ton

- Aluminum
  - The separated aluminum is assumed to be used in aluminum production. The energy requirements

for aluminum made from virgin raw materials and secondary materials are (14):

-- Virgin raw materials: 178,214 x 10^3 BTU per ton

-- Secondary aluminum: 80,868 x 10^3 BTU per ton

The energy savings from the substitution of secondary aluminum for virgin raw materials are:

(178,214 x 10^3 BTU/ton)-(80,868 x 10^3 BTU/ton) =
97,346 x 10^3 BTU/ton

- Newsprint

  - The energy savings are based in the substitution of a ton of waste news for ground wood pulp in newsprint manufacture. The energy consumed in the production of newsprint from ground wood pulp and waste news is (15):

-- Ground wood pulp: 22,897 x 10^3 BTU per ton

-- Waste news: 16,757 x 10^3 BTU per ton

The energy savings from the substitution of waste news for ground wood pulp are:

(22,897 x 10^3 BTU/ton)-(16,757 x 10^3 BTU/ton) =
6,140 x 10^3 BTU/ton

- Corrugated

  - The recovered corrugated is used in the manufacture of new corrugated. The substitution of old corrugated is assumed to be to the maximum extent feasible. In the maximum case, old corrugated is used as 20 percent of the feedstock for linerboard and 100 percent for the medium. Linerboard and medium are combined at a rate of 2.2 to 1.

    The energy consumed in the manufacture of corrugated from virgin pulp and the maximum recycle case is (16):

-- Virgin pulp: 23,800 x 10^3 BTU per ton

-- Maximum recycle: 19,418 x 10^3 BTU per ton

The energy savings in the maximum recycle case vis-a-vis the use of virgin are:

(23,800 x 10^3 BTU/ton)-(19,418 x 10^3 BTU/ton) =
4,382 x 10^3 BTU/ton

Less than half a ton of old corrugated is used to produce a ton of corrugated in the maximum recycle case. The adjustment in the energy savings to indicate the savings per ton of old corrugated may be calculated as follows:

$$(4{,}382 \times 10^3 \text{ BTU/ton}) \times (2.2) = 9{,}640 \times 10^3 \text{ BTU/ton}$$

- High-Grade Paper
  - The energy value is based on the substitution of high-grade paper for virgin pulp in tissue manufacture. The energy requirement for tissue production for virgin pulp and high-grade paper are (17), (18):
    - -- Virgin pulp: 40,000 x 10^3 BTU per ton
    - -- High-grade paper: 26,000 x 10^3 BTU per ton

The energy savings from the substitution of high-grade paper for virgin pulp are:

$$(40{,}000 \times 10^3 \text{ BTU/ton}) \times (26{,}000 \times 10^3 \text{ BTU/ton}) = 14{,}000 \times 10^3 \text{ BTU/ton}$$

Incineration with Energy Recovery

The assumptions on incineration are, (Personal communication. Steve Levy, U.S. Department of Energy, Washington, D.C. July 26, 1978):

- Solid waste has a thermal value of 10,000 x 10^3 BTU per ton
- Supplemental fuel requirements amount to 5 percent of thermal value of the input refuse
- Supplemental fuel: natural gas (thermal value: 500 x 10^3 BTU per ton of input refuse)
- Boiler efficiency: 50 percent

The energy generated may be calculated as follows:

$$[(10{,}000 \times 10^3 \text{ BTU/ton} + (500 \times 10^3 \text{ BTU/ton})] \times (.50) = 5{,}250 \times 10^3 \text{ BTU/ton}$$

To determine the energy conserved, the input energy of an alternative system must be calculated. The alternative is assumed to be a coal-fired boiler. It was assumed that boiler efficiency was 65 percent.

The energy produced may be calculated as follows:

$(5{,}250 \times 10^3 \text{ BTU/ton}) \div (.65) = 8{,}076 \times 10^3 \text{ BTU/ton}$

The energy conserved is the equivalent input energy saved minus the supplemental energy used. This value is:

$(8{,}076 \times 10^3 \text{ BUT/ton})-(500 \times 10^3 \text{ BTU/ton}) =$
$7{,}576 \times 10^3 \text{ BTU/ton}$

The net energy must include the energy used to haul the residue to a landfill. The residue is transported in a diesel fuel front-end loader. The truck's characteristics are, (Personal communication. Warren Gregory, Atlantic Equipment, Inc., Washington, D.C. June 20, 1978):

Capacity: 30 cubic yards (7.5 tons)

Mileage: 6 miles per gallon

The haul distance is 10 miles, including return. Energy conservation may be calculated as follows:

$[(10 \text{ miles}) \times (139 \times 10^3 \text{ BTU/gal})]\div[(6 \text{ miles/gal})\times(7.5 \text{ tons})] =$
$31 \times 10^3 \text{ BTU/ton}$

The calculation to adjust the energy use for residue disposal for the 75 percent reduction in weight may be done as follows:

$(31 \times 10^3 \text{ BTU/ton}) \times (.25) = 8 \times 10^3 \text{ BTU/ton}$

The net energy is:

$(7{,}576 \times 10^3 \text{ BTU/ton}) - (8 \times 10^3 \text{ BTU/ton}) = 7{,}568 \times 10^3 \text{ BTU/ton}$

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APPENDIX G

MODULAR INCINERATOR SELECTION GUIDE

A series of graphs were developed to assist in the evaluation of the cost-effectiveness of modular incineration with energy recovery. One graph was prepared for each of eight waste generators and were included as Figures 21 through 28 which are included at the end of this appendix. The generators are:

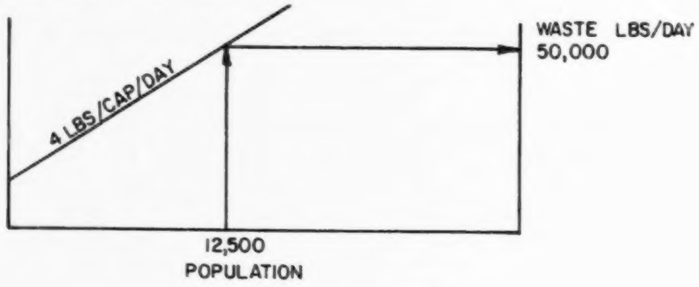
- Small Cities, 21
- Airports, 22
- Shopping Centers, 23
- Office Buildings, 24
- Garden Apartments, 25
- Universities, 26
- Prisons, 27
- Hospitals, 28

The graphs can be used to estimate the size of incinerator needed and approximate daily total costs. When compared to current solid waste disposal costs these figures can lead to the seclection of the most cost-effective approach. Use of the graphs is described below using Figure 21 for small cities as an example.

STEP ONE: WASTE QUANTITY

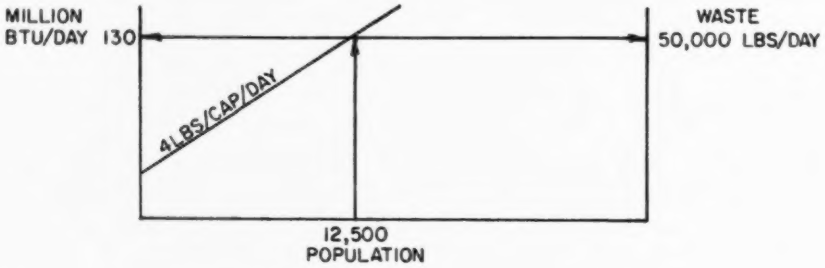
The left half of Figure 21 refers to waste quantity and associated potential energy recovery. If the quantity of waste disposal daily is known, find that weight on the right vertical axis of the left-hand graph, titled "Waste, lb/day".

If population and per capita daily waste generation are known they can be used to estimate waste generation. Find the population along the bottom axis. Draw a line vertically upward until it intersects the appropriate waste generation rate line. For this example, assume a population of 12,500 and 4 lb per person per day. Here the vertical line intersects the waste generation line, draw a horizontal line to the right vertical axis. The intersection of these lines is the waste to be disposed each day as shown below as 50,000 lb. Note: be careful to use the same number of days per week for both waste generation rates and disposal operation.



STEP TWO: ENERGY RECOVERY

To determine the potential energy recovery from this quantity of waste, trace the daily waste quantity horizontally back to the left vertical axis and read the energy recovery in millions of BTU per day. Note that the energy content of the refuse is assumed and shown as is the refuse boiler efficiency. This example yields a potential energy recovery of 130 million BTU per day.

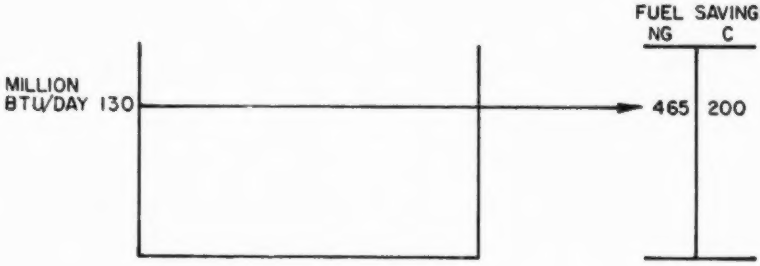


STEP THREE: FUEL SAVINGS

Next the value of fuel savings per day is estimated. This utilizes the central, vertical line in the figure labeled Fuel Savings. Fuel savings can be compared to natural gas or coal with the following prices assumed:

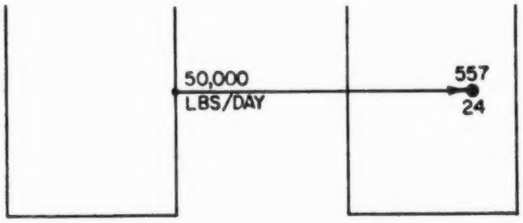
- Coal $1 per million BTU
- Gas $2.50 per million BTU

Fuel savings can be read from the graph or calculated by multiplying the daily energy recovered (STEP TWO) by the above prices or by local costs if different. Projecting the energy recovery quantity to the Fuel Savings line shows a daily savings of about \$465 or \$200 when compared to natural gas and coal respectively, assuming a 65 percent boiler efficiency for both. See example below:



STEP FOUR: INCINERATOR SELECTION

The size of incinerator is determined next by continuing horizontally to the left vertical axis of the right half of the graph labeled Unit Size. The intersection of the horizontal line and the axis is the daily capacity needed, in this case 50,000 lb (the waste generated). Continue the line to the right until it intersects one of the shaded areas. Each area represents a commercially available modular incinerator unit or combination of units capable of burning the quantity of waste in either 8 or 24 hours. The line in the example intersects the area as shown below.



This indicates that the waste could be burned in 24 hours (lower number) at an average total daily cost of \$557 (top number). Note: if the horizontal line does not intersect one of the shaded areas, select the lowest areas that is above the line.

STEP FIVE: COST ANALYSIS

Costs are now compared between the selected modular incinerator and current disposal costs. Daily incinerator costs are \$557. Fuel savings of \$200 daily for coal (assumed in order to be conservative) yield an overall daily cost of \$357. This gives a cost per ton of \$14.28. If current disposal costs exceed this figure, modular incineration appears feasible.

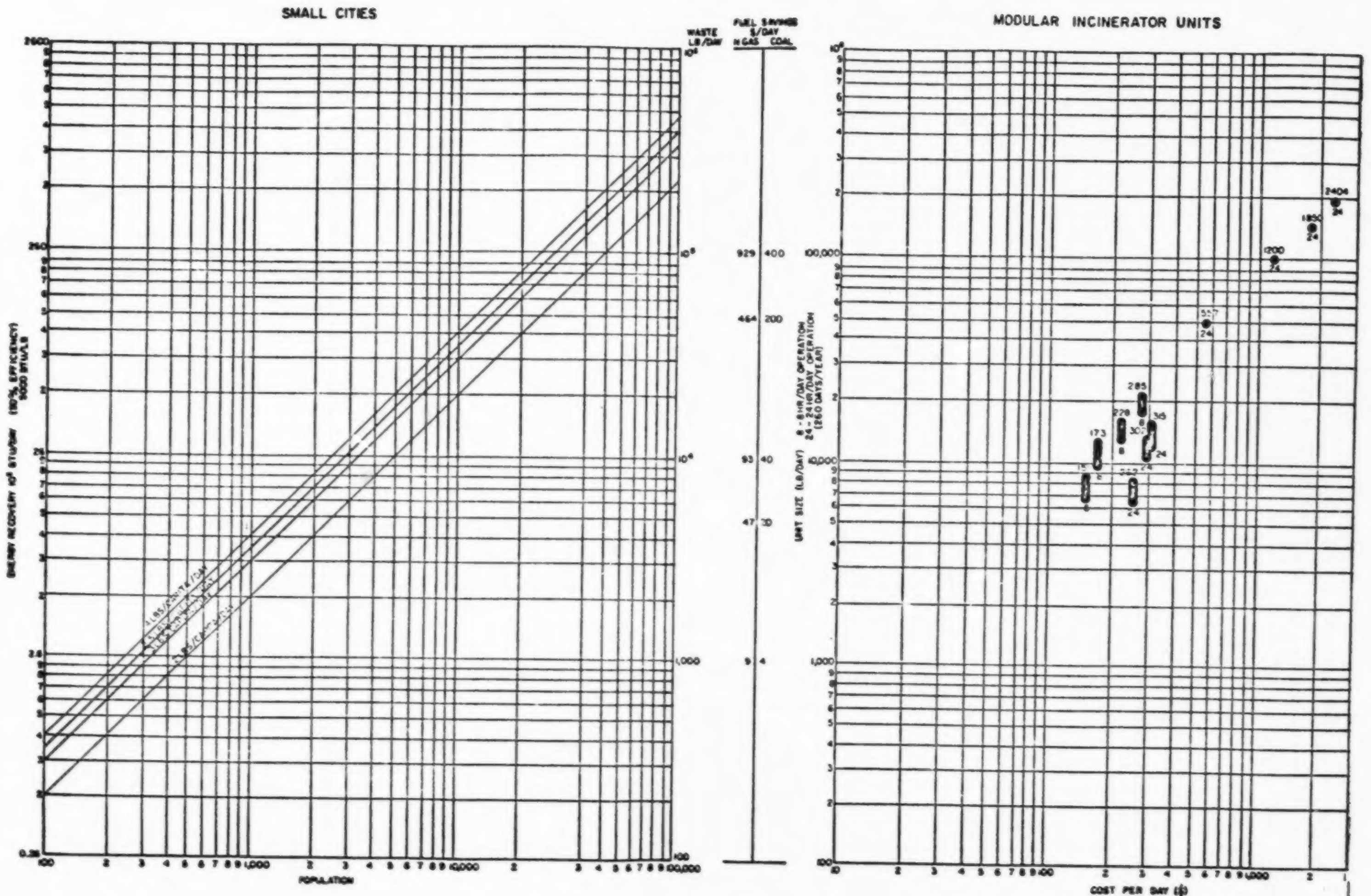


Figure 21. Modular incineration selection guide for small cities.

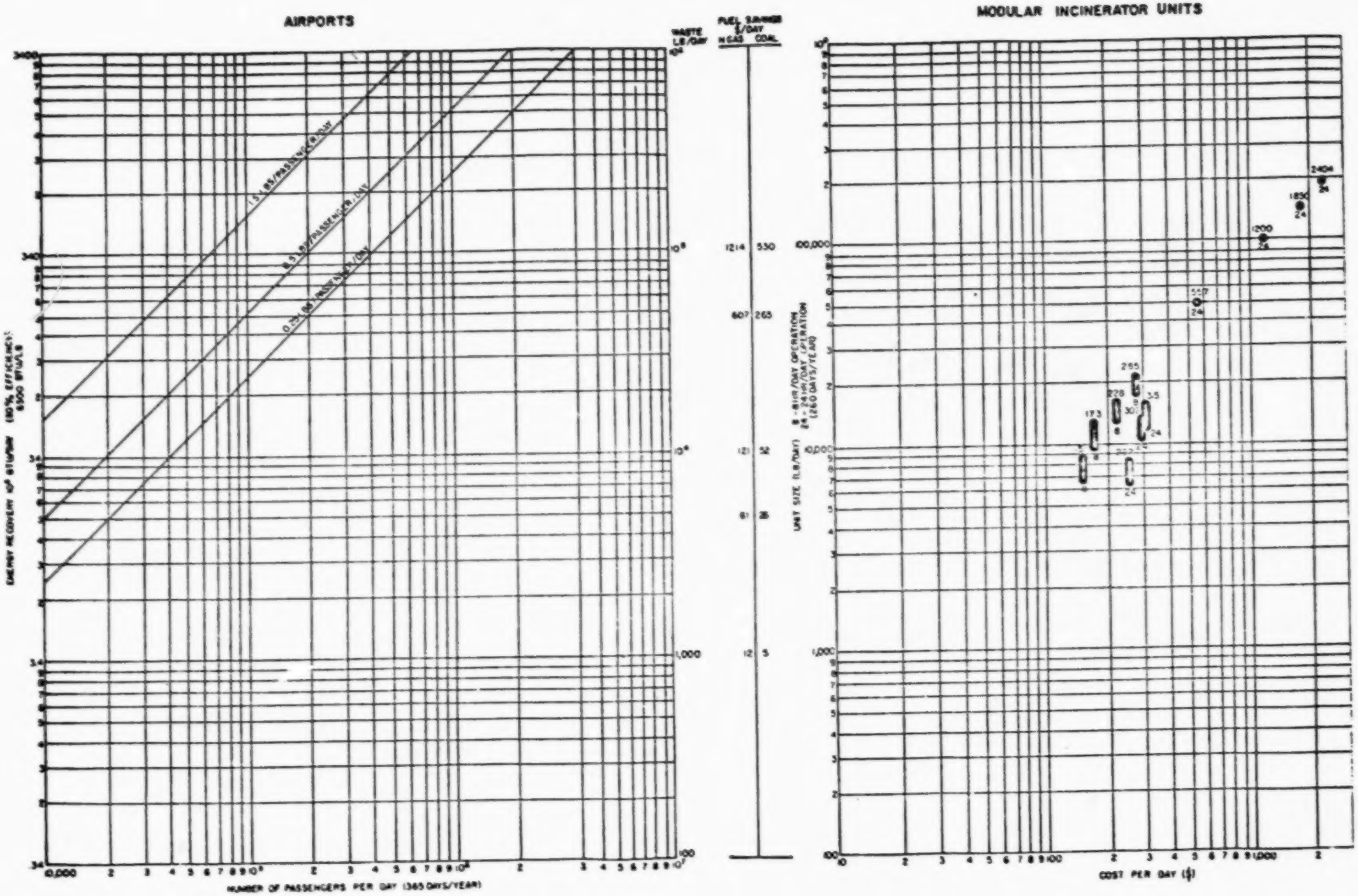


Figure 22. Modular incineration selection guide for airports.

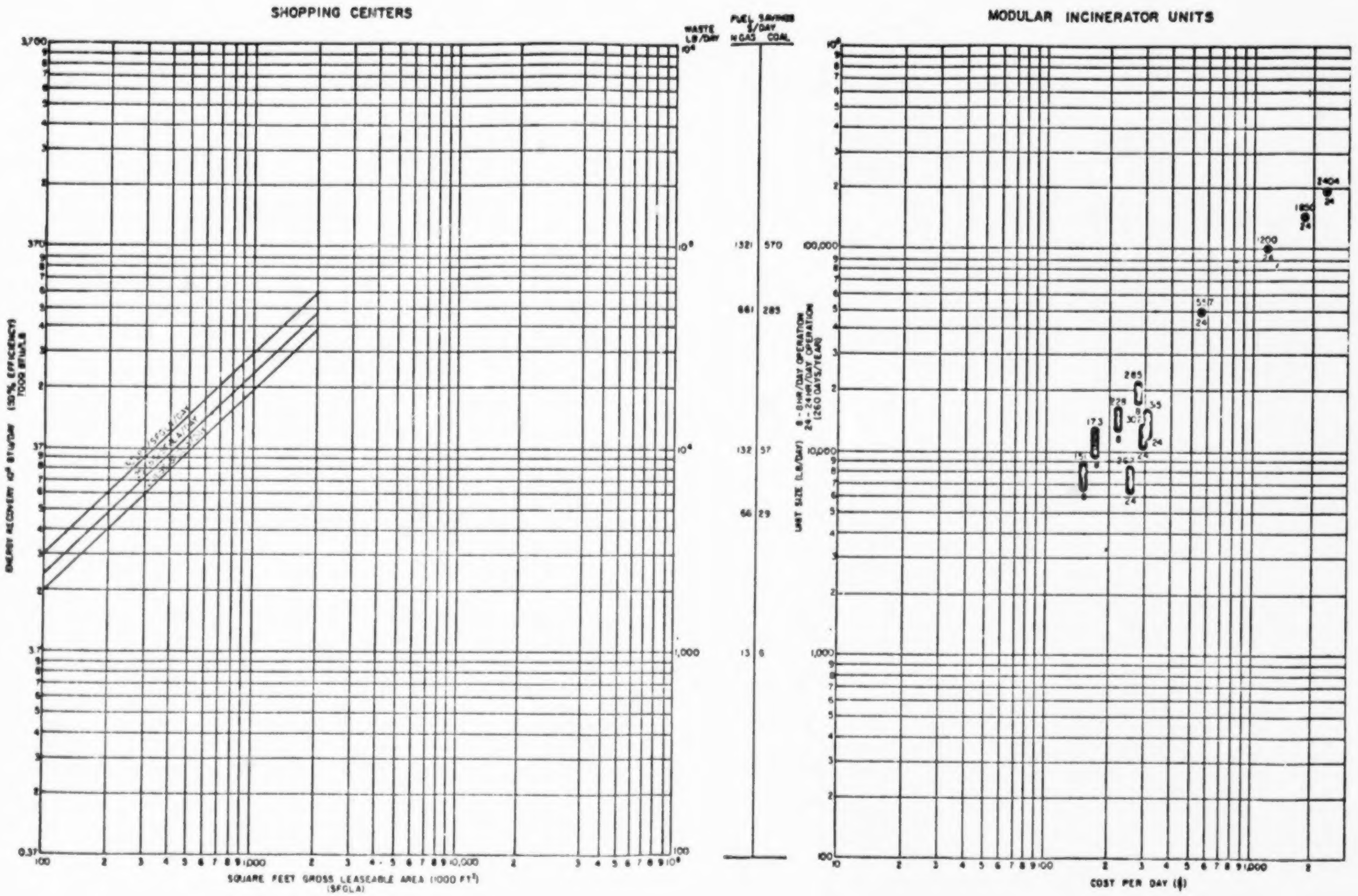


Figure 23. Modular incineration selection guide for shopping centers.

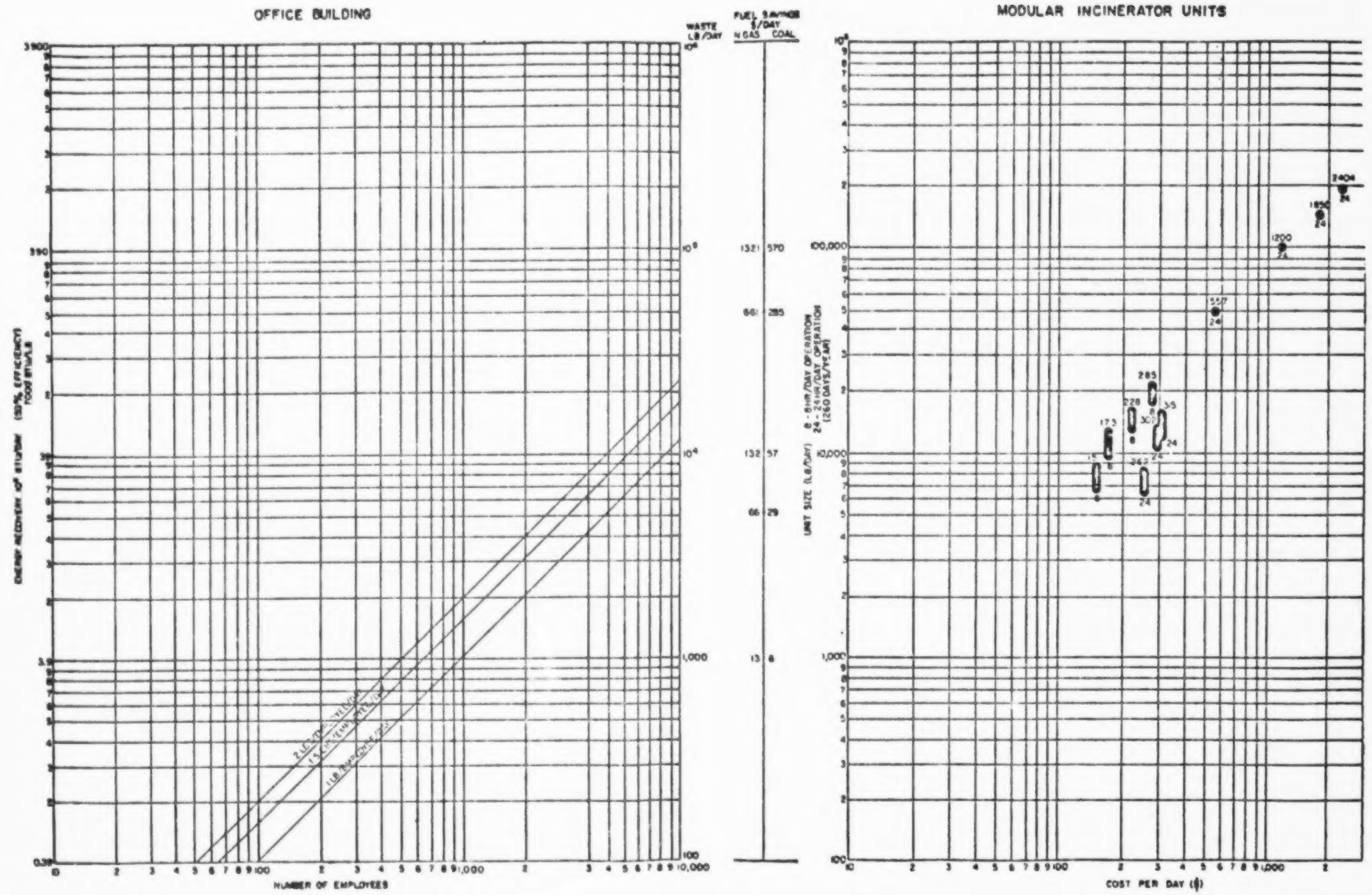


Figure 24. Modular incineration selection guide for office buildings.

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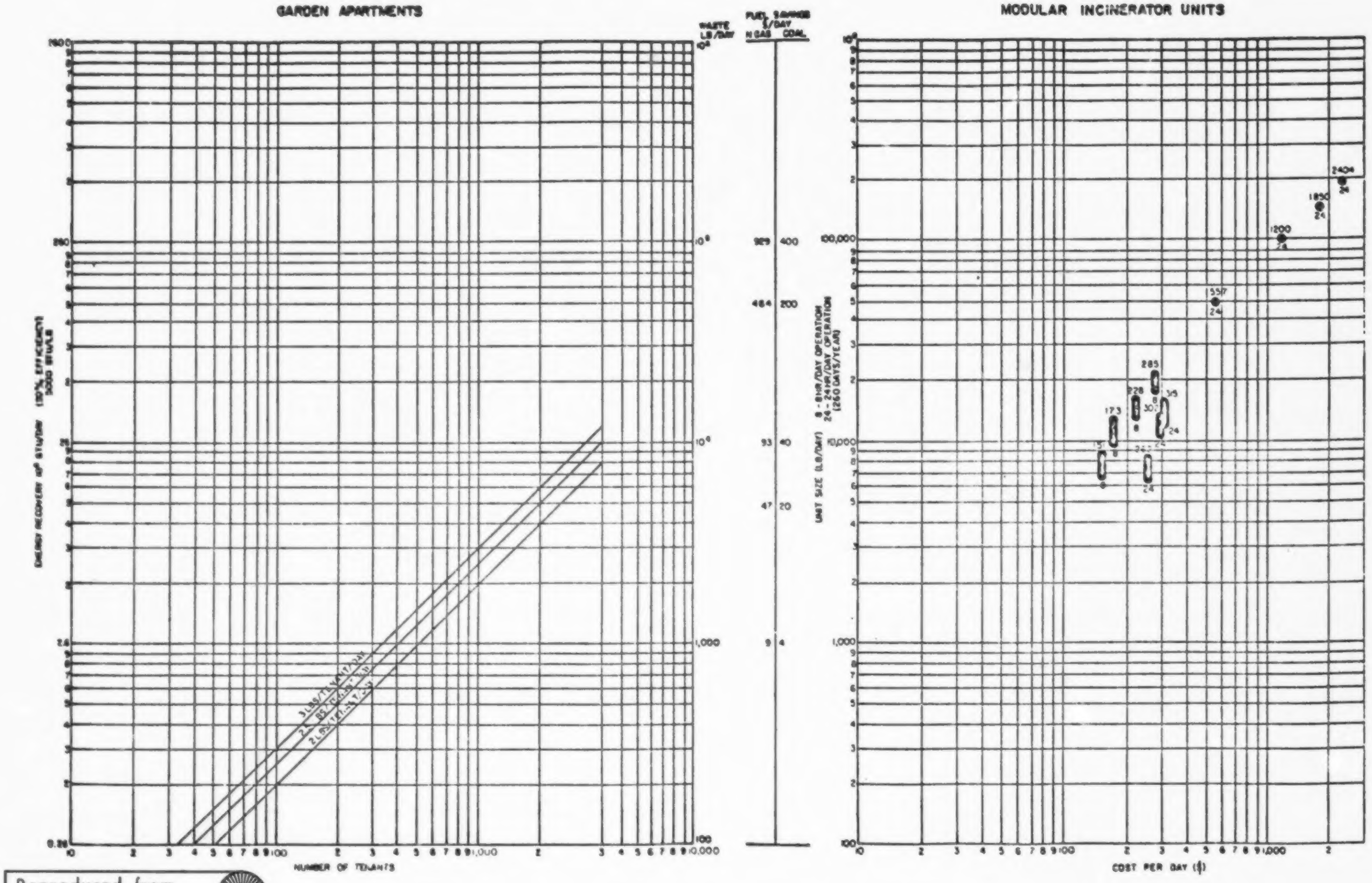

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Figure 25. Modular incineration selection guide for garden apartments.

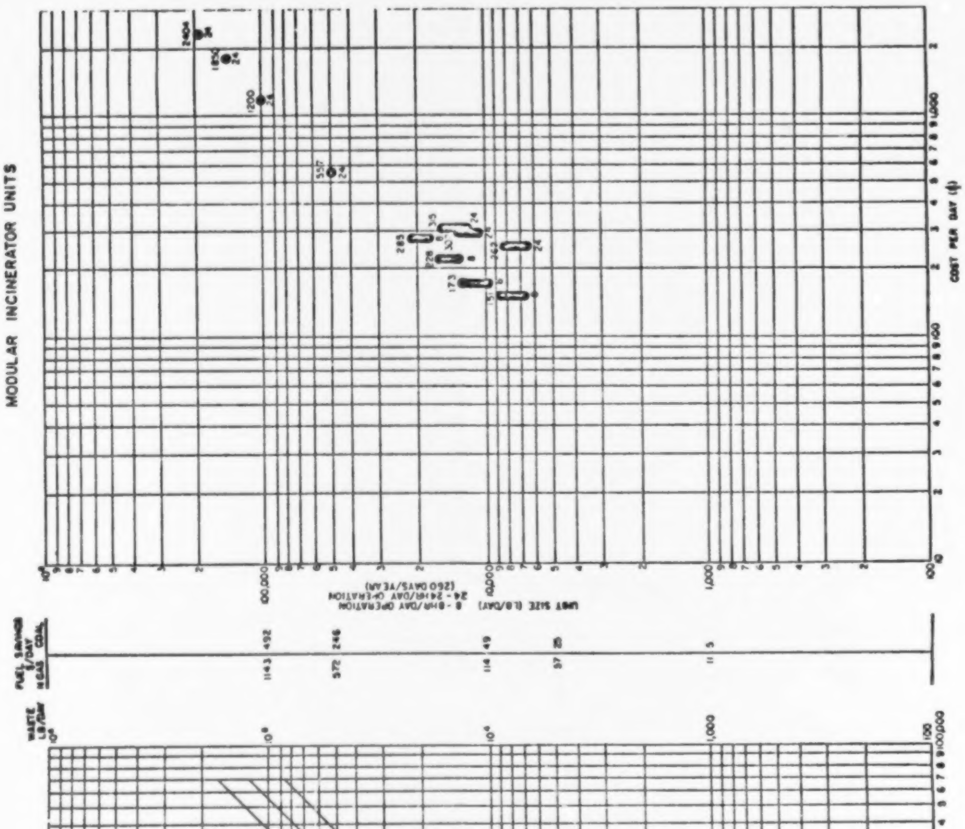

Figure 26. Modular incineration selection guide for universities.

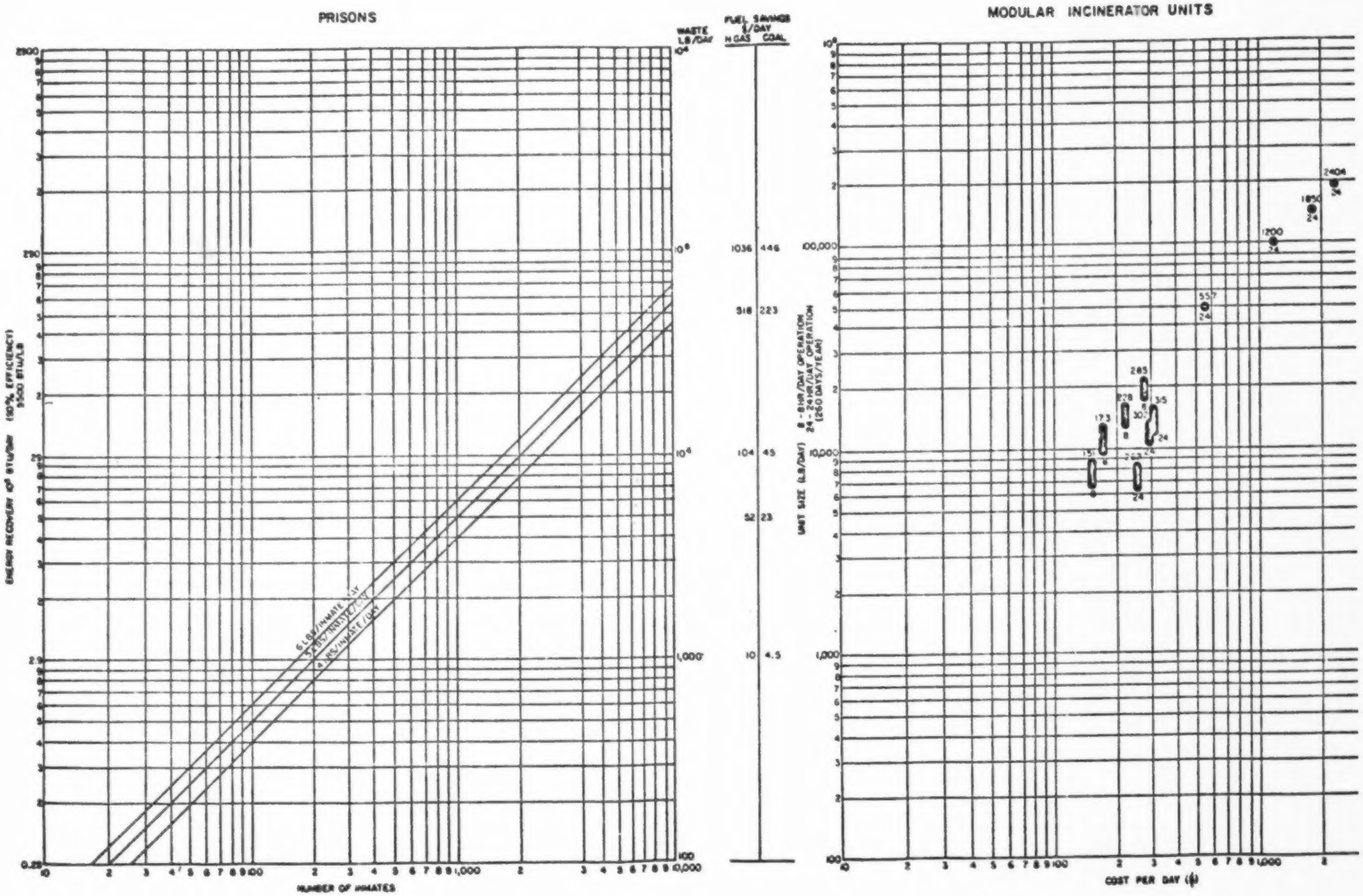

Figure 27. Modular incineration selection guide for prisons.

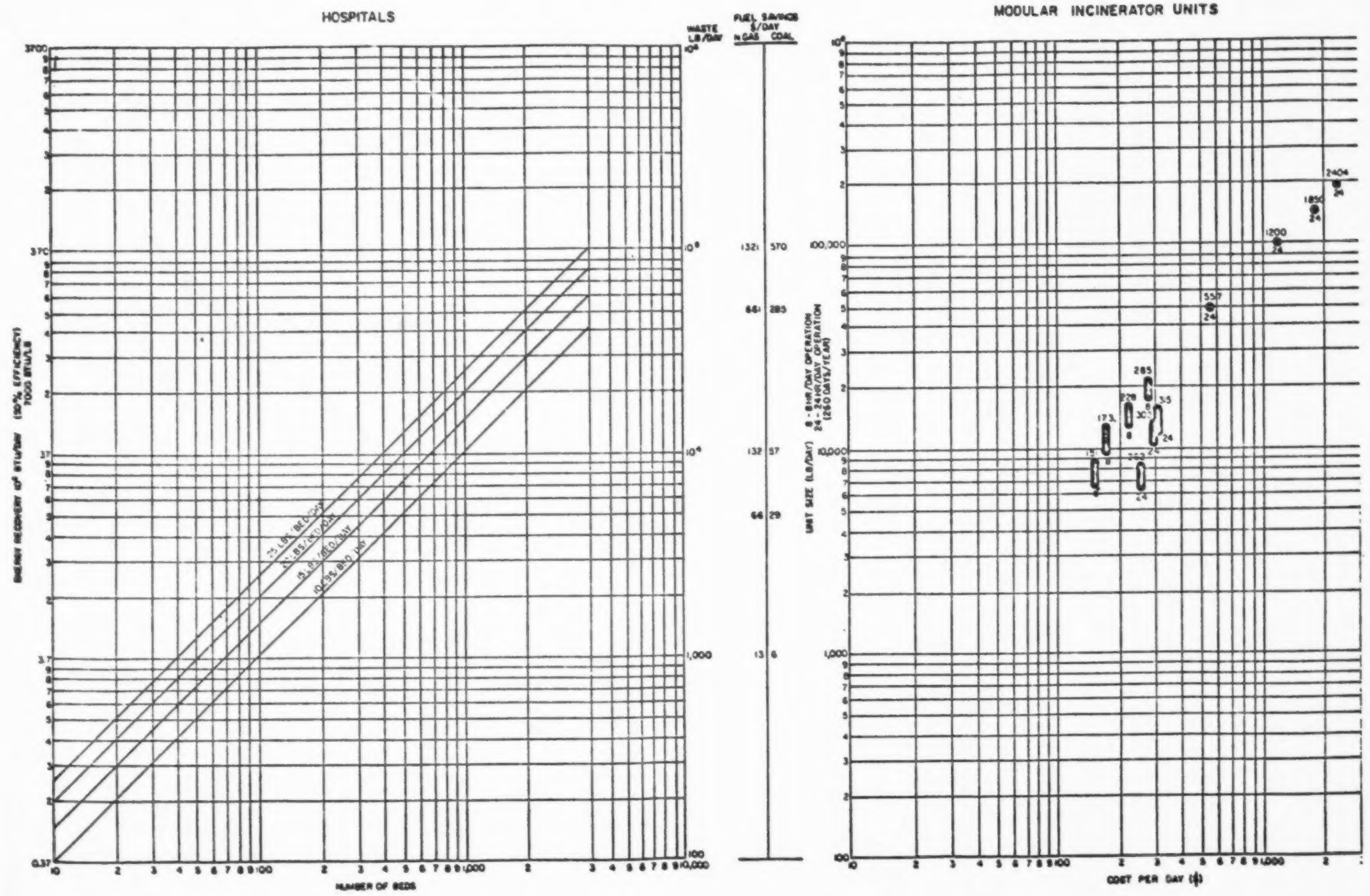

Figure 28. Modular incineration selection guide for hospitals.